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## WATCHKEEPING STUDIES ON A NUCLEAR SUBMARINE.

### FINAL REPORT.

by

## NOTE

The views and opinions expressed in this report are the authors' and do not reflect those of the Royal Navy or Ministry of Defence.
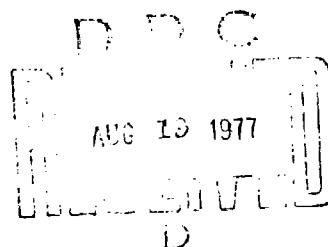
# FOREWORD

It has been shown clearly in laboratory investigations into the effects on mental efficiency of the'rotating' and 'fixed' watchkeeping systems used in Royal Navy ships, that in the former a substantial degree of variability in performance occurs in response to the persisting diurnal rhythms, whereas in the latter, a degree of adaptation of these rhythms occurs which stabilises the performance level considerably. The extent of changes in diurnal rhythms induced by various rotating and fixed watchkeeping systems during the very long underwater patrols now undertaken by submarine crews had not previously been investigated in the Royal Navy, and the studies reported here had the aim of determining whether, in this new situation, effects similar to those found in the shorter shore-based studies would be seen. An important factor in the submarine environment was the concomitant absence or reduction in strength of external physical Zeitgeber such as sunlight and day/night temperature variation.

It was appreciated from the outset that many unknown or uncontrollable variables would be present in these studies and, accordingly , only the procedures of temperature data collection and self-reporting of sleep patterns were attempted. Due primarily to small numbers of subjects in each watchkeeping group and the presence of major uncontrollable variables, no firm conclusions could be drawn from the results. However it was possible to show that temperature rhythm amplitudes became compressed in most subjects on a rotating system, and that the degree of desynchronisation of these rhythms with shipboard time as the patrol progressed varied widely between subjects from no change in rhythm at all to complete desynchronisation. It was also demonstrated that sleep patterns changed considerably, with a reduction in the amount of night sleep taken in most cases, and in some individuals the accumulation of a considerable sleep deficit. The significance of some of these changes for operational performance may be considerable, as may the different degrees of adaptation to fixed watchkeeping systems which were also noted.

It must be concluded from the studies that while the changes observed are sufficient to suggest that in some circumstances, operational performance may be compromised, much more extensive physiological measurements are required under conditions where close control over experimental variables can be applied, before definite conclusions can be drawn, and the Navy given results of sufficient validity to allow them to act in the real situation. It is clear that to achieve this aim further primary studies must be conducted in the laboratory, with the results being validated secondarily at sea. The Navy has its own facilities with which to conduct such investigations in its Environmental Medicine Unit at the Institute of Naval Medicine, and it is to be hoped that in the light of the findings reported here from the real situation, such studies will be progressed with vigour.

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D M DAVIES OBE RN
Surgeon Commander

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# SUMMARY

1. In two prolonged patrols on a nuclear submarine, on-watch body temperatures were obtained at hourly intervals from (a) UC ratings following a 'rotating' 1 in 3 watchkeeping schedule with a 3-day cycle and (b) officers following 'standing watch' routines. A sleep/activity log was kept by each subject.

2. Both 'graphical' and computer analyses of the temperature data obtained from the UC ratings showed that the amplitude of the circadian temperature rhythm was markedly reduced during the patrol, only one subject proved a clear exception to this rule. In addition, the temperature rhythm of at least one subject became completely 'out of phase' with shipboard time.

3. The sleep of the UC ratings (a) varied considerably in amount, and (b) was taken less often in 'night' hours than the watchkeeping schedule actually allowed. In some cases the total amount of sleep taken was undesirably low in particular periods of the patrol.

4. Of the three officers operating a standing duty schedule requiring 'unusual' hours of sleep, two showed adaptation to their altered work/rest routine in terms of temperature rhythm changes, but the third did not. Thus the advantages of 'standing-watch' over 'rotating' watchkeeping schedules is not proven at present.

5. It is concluded that although it is not possible to say whether, or to what extent, performance efficiency was affected by the physiological changes observed, the latter were similar to those seen after rapid transition through several time-zones and during isolation in caves or bunkers, and suggest that a state of internal desynchronisation of circadian rhythms occurred in most subjects. It is proposed that further, more extensive physiological measurements on personnel on different kinds of watchkeeping schedule would enable the magnitude of this desynchronisation to be assessed, and its significance for operational efficiency to be evaluated.

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# INTRODUCTION

Extensive studies of Naval watchkeeping schedules in shore based trials (summarised in Ref 1) have demonstrated that, under the 'traditional' 3-watch rotating system, the normal rhythm of body-temperature persists for a period of 12 consecutive days of watchkeeping, and that this rhythm is accompanied by clear and relatively substantial fluctuations in mental efficiency as measured by performance on simulated sonar and communications tasks. It has also been established in these studies that under various fixed (or 'standing-watch') systems the temperature rhythms adapt at least partially to resulting alterations in regular daily sleep/waking schedules, and it has been suggested that the associated alterations observed in on-watch trends in mental efficiency would represent a worthwhile gain in the operational situation, particularly on extended voyages. The aim of the present studies was to determine whether, over such an extended voyage represented by a nuclear submarine patrol, the normal temperature rhythm still persisted under the same rotating watchkeeping system investigated in the shore-based trials. Depending on the results obtained, there might then be grounds for suggesting the adoption of an alternative, 'standing-watch' system for those sections of the crew who at present follow the rotating schedule.

# METHOD

Oral temperatures were recorded by 'Dependatherm' electronic thermometers at hourly intervals during each watch kept by selected personnel throughout the entire submerged period of two patrols. In the first patrol the 12 UC ratings who kept watch on the 'traditional' systems in the Sonar Room served as the subjects (the schedule for this system is shown in Figure 1). In the second patrol the same section of the crew was studied, and, for comparison, temperature readings were also obtained from four Seamen branch officers who were acting as 'officers-of-the-watch' on 'standing watch' duty-schedules.

Each subject completed a record form each day (see Fig 2), on which hours of duty, 'clean-ship', recreation and sleep were recorded by a simple 'barograph' method, together with the on-watch temperature readings obtained. In the Sonar Room the senior rating in charge of each of the three watches of 4 ratings was made responsible for ensuring that these forms were correctly completed. The whole operation was under the personal supervision of the ship's M.O.

# RESULTS

The results will be presented in two sections. In Section A sleep amount and patterning, and those aspects of the temperature rhythm that could be ascertained from graphic representations of the data (in reduced form) are analysed. In Section B the supporting findings of a detailed statistical analysis of all the temperature data carried out by computer using a specially devised programme are described. [ The results obtained from a short performance test of card-sorting which were briefly described in the Interim Report will not be presented here, since they are largely irrelevant to the question of operational efficiency at the real-life task. ]

First Patrol

All subjects remained in good health throughout the patrol, and complete recordings were obtained over a total period of 48 days from each of them.    However, since it was impossible for the M.O. to maintain adequate supervision right round the clock, the data from that 'watch' of 4 subjects over which control was less than adequate was discarded from the analysis on the grounds that some of the entries may possibly have been erroneous.    Thus what follows is based on a total of 8 subjects.

1.  Sleep

   (a) Sleep Amount   Owing largely to the nature of the watchkeeping schedule (cf Fig 1) the amount of sleep obtained in any given 24-hour period varied considerably.   However, the cycle of watches is arranged in such a way as to allow personnel to 'make up' for sleep lost on night watches by sleeping during the day-time (in the present case all of this 'day' sleep was taken in the afternoon or evening periods).   To the extent that the subjects made up their sleep in this way one might expect a 3-day total sleep duration of some 20-25 hours, the exact amount depending on the individual's personal sleep requirements.

The 3-day sleep totals for each subject were therefore examined to determine (i) the actual overall mean amount per 3-day period, (ii) the extent of variation about this mean and (iii) whether there was any evidence of systematic trends in this variation during the period of observation.

      (i)  The overall mean number of hours slept by each subject per 3-day period ranged from 18.5 to 23.1 hours, with a grand mean of 21.2 hours.   Thus no subject could be said to have been chronically sleep-deprived, and the grand mean is fairly typical of the population at large.

      (ii)  The variation about the mean in successive 3-day periods was, by contrast, quite considerable.   The typical range of variation for any subject was plus or minus $4\frac{1}{2}$ hours of his overall mean, though two subjects showed a range of variation of plus or minus 7 hours.   The minimum number of actual hours slept in any particular 3-day period by any subject was 13, which could be considered as undesirably low.

      (iii)  Trends during the patrol: of the 8 subjects, 2 showed a progressive tendency to take less sleep as the patrol continued, 4 showed a progressive tendency to take slightly more, and the remaining 2 showed evidence of a reduction followed later on by a subsequent return to initial levels.   Thus there was no trend common to all subjects.

   (b) Sleep Patterning.   Because the watchkeeping schedule imposes two nights out of 3 of reduced sleep, the proportion of sleep taken during 'natural' (ie 'night') hours (defined for present purposes as 2400-0800) cannot normally be expected to be much greater than approximately $\frac{2}{3}$ of the total.   The actual proportion of such 'night' sleep was computed for each subject for each 3-day period, and the grand average is shown in Figure 3 as a function of time on patrol.   From this graph it will be evident that (after the first 9 days) the proportion of 'night' sleep tended to fall relatively regularly from about 70% to 50% as the patrol progressed.

Although there were considerable individual differences, a similar general tendency was evident in all cases (in one subject the decline was temporarily reversed during the 6th to 8th week period of the patrol). A Friedman two-way analysis of variance by ranks showed that the differences between the mean 3-day proportions of 'night' sleep were highly significant statistically ($p < 0.001$), and rank correlation of the means with period number demonstrated that the observed trend represented a genuine decline for the group as a whole (rho = -0.87, $p < 0.01$).

Examination of the individual subjects' sleep/activity logs indicated that this tendency to distribute sleep more evenly over 'night' and 'day' periods as the patrol continued was effected by cutting down on the time spent in bed on the two nights when night watches were carried out. This behaviour was particularly evident on the night when the duty period was 0400-0800; in this case it was not uncommon for subjects to remain awake all night.

Although the significance for performance efficiency of this change in sleep patterning is not known, it should perhaps be pointed out that 'day' sleep which is substituted for lost 'night' sleep may not be of the same 'quality' and that, in consequence, a state of partial sleep deprivation may possibly have accumulated in the present subjects.

## 2. Body-temperature

(a) **Treatment of data.** 384 temperature readings were obtained from each subject. Since this number was clearly too large to deal with graphically, the data were reduced by averaging the four readings taken on each watch to obtain an estimate of the mean level of temperature during the duty spell. The resulting 6 readings per 3-day period were then plotted on a single 24-hour time base to give a graphical representation of the '24-hour' temperature rhythm for the period (the basic assumption underlying this procedure is, of course, that no changes in the rhythm were occurring during a 3-day period; although this may or may not have been true, in most cases the changes that were observed over the 48 days (see below) took place at such a slow rate that for practical purposes the assumption is probably justified.

(b) **Average trends.** The '24-hour' rhythm (as defined above) for each successive 3-day period is shown in Figure 4 averaged over all subjects. It will be seen that whereas the shape of the curve was quite reasonably 'normal' at the beginning of the 48-day period (see Figure 5, which shows the normal rhythm in detail) there was a gradual, if slightly erratic, reduction in its amplitude as the trial progressed, with some slight evidence of a re-increase in amplitude at the end. This trend could, of course, be artefactual, since such an effect might well appear if the rhythm of each of the 8 individual subjects on whom the mean values are based was changing, not in amplitude, but in phase. Thus it is necessary to examine each subject's records separately.

(c) **Analysis of individual trends.** The individual subjects' records were examined in respect of (i) mean level, ie the '24-hour' (3-day) average (ii) 'range', ie the difference between minimum and maximum readings regardless of phase and (iii) 'phase', ie the timing of the peak and trough of the rhythm in relation to the 24-hour time scale.

(i) Mean level. No very marked changes were observed in this measure. In 3 subjects there was a general tendency for the mean level to rise slightly over the whole, or at least part of the 48-day period; in 3 subjects there was a tendency for the level to fall slightly, and in the remaining 2 subjects there was no obvious trend.

(ii) **Range**. In all except one subject (where no change was evident) there was a definite tendency for the range to decrease over the whole, or at least the major part of the 48-day period. In some cases this trend was quite regular, in others somewhat erratic. Among the 7 subjects who showed this decrease, the value of the range at the start of the patrol varied from $1.0^{\circ}$ to $1.6^{\circ}$ F. The declines in the range were between $0.4^{\circ}$ and $0.7^{\circ}$ F; these declines represented decreases of from 33% to 50%.

In view of the fact that all but one subject exhibited this reduction in range, it seems justifiable to express the trend as an overall mean for all 8 subjects; this mean trend is shown in Figure 6. Analysis of variance by ranks showed that the differences between the mean 3-day ranges were highly significant statistically ($p < 0.01$); and rank correlation of the means with period number demonstrated that the observed trend represented a genuine decline for the group as a whole ($rho = -0.70$, $p < 0.01$). Thus it would appear clear that the reduction in the amplitude of the mean temperature rhythm was not artefactual.

In order to determine whether the 'flattening' of the rhythm indicated by the reduction in its amplitude resulted solely from an increase in the values of 'night' readings (due to the fact that at this time the subjects were active when they would normally have been sleeping), a separate examination was made, for the 7 subjects showing a decline in range, of the values obtained for each of the 6 watch-times. The observed directional changes in these values are given in Table 1.

Whereas Table 1 suggests that the 'flattening' of the temperature rhythm was indeed largely mediated by increases in the values of 'night' readings, it also shows that this was not the sole cause of the effect, since in many cases there were decreases in the values of 'day' readings also. It is noteworthy that these decreases were most common in the 1200-1600 watch, a period when, in 'normal' circumstances, temperature is near its highest level, but also the one in which, in the present situation, it was common for the subjects to make up their sleep on days when they were free of duty at this time. Thus although it does not appear that all the 'flattening' was due directly to concomitant activity at the specific times the readings were taken, it is nevertheless possible that it was in fact indirectly related to the overall rest-activity pattern over the 3-day period.

(iii) **Phase**. Determination of the phase of a rhythm by visual inspection is a notoriously difficult operation, since it depends on identification of 'peaks' and 'troughs' in data which may be too 'noisy' to allow this to be carried out reliably. However, certain tentative conclusions can be drawn at this stage. These are:

> 1. At the start of the observation period the phase of the temperature rhythm of all subjects was 'normal', ie the peak occurred in the late afternoon/evening period, and a clear trough was evident around 0400-0500.

> 2. In one case only could the rhythm definitely be said to remain 'normal' in phase throughout the patrol (this subject was the same one in whom no evidence of 'flattening' was found either).

> 3. In one case the results suggested that the subject's temperature was following a 'free-running' or 'natural' circadian rhythm throughout the patrol, with a period of approximately 24.5 hours. Thus after

24 days this subject's rhythm was about $180^0$ out of phase with the normal.

4. In the remaining 6 cases no definite statements could be made about the normality or otherwise of the phase, since the curves were too 'noisy'.

## Second Patrol

This took place nearly a year after the first patrol. The main subjects were again the 12 Sonar Room ratings; however, for comparison purposes, additional readings were obtained from 4 officers, each assigned to a different 'standing' watchkeeping schedule. The period of observation was 46 days (30 in the case of the officers), and the procedure was identical with that in the first patrol.

During this second patrol there was a mild epidemic of a presumed viral infection, characterized by high temperatures and malaise. This illness affected most, if not all of the Sonar Room subjects (up to 4 of whom were turned in at any one time). Thus the data from this group are somewhat fragmentary. Since the illness itself, and the extra work load imposed by this on the subjects who were not ill may have influenced the results obtained, these should be treated with caution.

## Sonar Room Subjects

1. Sleep

   (a) Sleep amount. Excluding periods off sick, the results for this measure were as follows:

   (i) The overall mean number of hours slept by each subject per 3-day period ranged from 16.4 hours to 33.5 hours, with a grand mean of 25.3 hours. Thus the range was greater, and the grand mean higher than in the first patrol.

   (ii) The variation about the mean in successive 3-day periods for any subject was typically about plus or minus $5\frac{1}{2}$ hours of his overall average (ie slightly greater than in the first patrol). However, 3 subjects showed a range of plus or minus 8 hours or more. Thus the actual number of hours slept in particular 3-day periods was in some cases undesirably low. Indeed, one subject reported having had only $5\frac{1}{2}$ hours sleep over one 3-day period in the middle of the patrol; this constitutes severe sleep-deprivation.

   (b) Sleep patterning. In contrast to the first patrol, the proportion of 'night' sleep remained fairly constant throughout the observation period in all but one subject, in whom the proportion fell from 65% to around only 40% in the middle of the patrol, with a subsequent partial 'recovery' to about 55% by the end. The overall grand mean proportion of 'night' sleep was slightly less than 60%, although there were considerable individual differences in this figure.

This difference in sleep patterning in the second patrol may, of course, have been due to the effects of the illness referred to earlier. However, it is felt more likely that further experience on intervening patrols had led subjects to adopt a 'personal' sleep pattern (which in some cases involved less 'night' sleep than theoretically possible)

that appeared as soon as watch-keeping commenced. The evolution of this 'personal' sleep pattern may well have resulted from the realisation that it was useless to lie in bed trying to sleep at 'conventional' times when sleep was not in fact obtained.

2. Body-temperature

(a) Trends during the patrol

(i) '24-hour' rhythms. Despite the gaps in the records caused by absence in sick bay, it was possible to identify several 3-day periods during which 10 particular individuals were all following their usual duty schedule, and were apparently fit. Thus it was possible to use the data from these 10 subjects to compute a limited number of mean '24-hour' rhythms; these are shown in Figure 7. It will be seen that the same trends noted in the first patrol were also evident in the present one, namely, a change from a 'normal' rhythm at the beginning of the patrol (estimated in this case from the readings over the first 6 days) to a much 'flatter' rhythm later on, and a slight recovery in amplitude towards the end.

(ii) Mean level. There were no ascertainable systematic trends through the patrol in this measure either in the group as a whole, or in any of the individual subjects.

(iii) Range . In all except one subject there was a definite tendency for the range to decrease over the whole, or at least the major part of the 46-day period. Near the start of the patrol the value of the range varied from about $0.7^{\circ}$ to $1.5^{\circ}$ F for individual subjects. The declines in the range from this point up to near the end of the patrol were between $0.1^{\circ}$ and $0.9^{\circ}$F; these declines represented decreases of from 9% to 83%. Figure 8 shows the average values of the range in successive 3-day periods. These values are based on different N's in different periods, because of the absence in sick bay of certain subjects. However, the overall downward trend is clear, and the fact that this trend is not biassed by the differential sampling is demonstrated by the positions of the 6 averages for the 10 particular individuals from which the mean '24-hour' rhythms in Figure 7 were calculated. The differences between these 6 latter averages were found to be highly significant by the Friedman test ($p < 0.01$).

Thus, apart from the greater degree of individual variation, these results are very similar to those obtained in the first patrol, and reinforce confidence in the genuineness of this 'flattening' phenomenon.

(iv) Phase. Because of the gaps in the records no attempt was made at this stage to determine whether or not there were any apparent shifts in phase during the patrol.

Officer subjects

The hours of duty of each of the four officers were different in each case. These hours, and the sleep patterns adopted by each subject (which tended to be relatively constant throughout the patrol) are given in Table 2.

In order to simplify the data, and to make it readily comparable with that from the Sonar Room subjects, the mean on-watch temperatures for each subject in each of the two periods of duty performed by him each day have been averaged over 3-day periods, and

are shown in Figure 9 (note: in the first 5 day period the readings were taken at different times on each day since the officer subjects had not, at this time, yet taken up their regular duty schedule).

__Subject 01.__   This subject was essentially on 'day' work, though he did not finish his second turn of duty until after midnight.   Perhaps because of this late finish he did not go to bed until 0300.   Nevertheless his 'main' sleep was in the usual 'night' hours, and one would therefore expect to see only a small change from a normal rhythm in this case if such a routine were to be followed on shore.

According to the graph of the 'normal' temperature rhythm (cf Figure 5), there should be little difference between the temperature readings at the two times for which mean values were assessable in this subject (1100 and 2200 respectively).   Reference to Figure 9 shows that this was in fact the case, and that there was no obvious evidence of any systematic change in this difference throughout the observation period.   Thus at this stage it cannot be said whether this subject 'adapted' to his work-rest schedule to any significant extent.

__Subject 02.__   The fact that this subject had to rise early at 0400 each day might, on previous evidence (Ref 2) lead one to expect a gradual phase-advance of the normal temperature rhythm by about 3 hours if this routine were to be followed on shore (although the second sleep period from 1300-1700 was an 'unknown factor' in the present case).   Figure 9 suggests that the extent of the difference between the mean readings at 0630 and 1930 increased slightly as the patrol progressed.   Since a straightforward phase advance would show up as a _decrease_ in this difference (cf Fig.5), it is not clear at this stage what form the adaptation of the temperature rhythm was taking in this subject.

__Subject 03.__   This subject followed normal 'civilian' hours of work and sleep and one would not therefore expect to see any changes in the normal rhythm if the general conditions aboard ship were not such as to affect it in any way.   Figure 9 suggests that no change in fact occurred, since the difference between the mean temperatures for the forenoon and afternoon periods during which readings were obtained remained approximately constant throughout the observation period.

__Subject 04.__   The delay in bedtime occasioned by the 0030-0430 duty period assigned to this subject would, on the basis of previous trials over a shorter period with a similar watch (Ref 3), be expected to produce first a 'flattening' of the rhythm, and subsequently (perhaps) a complete readjustment, resulting in an eventual delay of some 6 hours in its phasing.   Figure 9 shows that these changes did indeed occur as predicted, in that the difference between the mean temperatures obtained for 0230 and 1730 first decreased, and then gradually increased again _but with reversed sign._   The observed phase shift can be estimated from reference to Figure 5 as being of approximately the 'expected' order, ie 6 hours.   Thus the general expectations for this subject were confirmed, though it is difficult to determine at this stage exactly how long the 'readjustment' process took to complete.

Section B - Computer analyses of the temperature data

Analytical procedures

Circadian rhythms are commonly described by sine curves and a computer programme for fitting such functions has been used to analyse the present data, which, because of the

watchkeeping schedules, were obtained on a systematic, but unequally-spaced schedule. Such a schedule might introduce artefacts which are peculiar to the sampling pattern rather than representing changes in the rhythm of the subject occasioned by the watchkeeping schedule per se. Thus, to determine the influence of the sampling schedule alone on the temperature rhythm, the mean 'normal' temperature curve (see Fig 5) was subjected to the same procedures. Points from this mean curve at times corresponding to the present data points were used as a standard; ie the same sampling pattern was followed, but without the possibility of the watch-keeping schedule influencing the form of the temperature changes.

The mean normal temperature curve will be referred to as the 'Standard Curve'. The 8 UC ratings from the first patrol will be referred to as S1A – S8A, and the 12 UC ratings from the second patrol as S1B – S12B. The '3-day periods' will be referred to as 'cycles', numbered consecutively from the beginning of a patrol.

## The Programme: Periodogram

This programme, unlike the 'classic' method of harmonic analyses (which was also applied to some of the data and is described in a fuller report on the results of the computer analyses in Ref 4) allows unequally-spaced points to be fitted by a sine curve. Thus the data may be analysed in the actual order in which they were obtained. Also, since it is possible to process incomplete or infrequently-sampled series of data by this programme, the readings from the second patrol (which had just these limitations) can be analysed in a comparable manner to those obtained in the first patrol.

The curve fitted is as follows:

$$y = a_0 + a_1 \cos \omega t + b_1 \sin \omega t$$

where y is the estimated value; $a_0$ is the harmonic mean; $a_1$ is the coefficient of the cosine term; $b_1$ is the coefficient of the sine term; $\omega = \dfrac{2\pi}{\text{period}}$ and the period is variable; t is the time in hours.

Significance of ⸱⸱ assessed by the magnitude of the F-ratio in an analysis of variance method.

$$F \text{ ratio} = \frac{S S D_0 - S S D_1}{S S D_1} \times \frac{N - 3}{2}$$

where $S S D_0$ is the sum of squared deviations from the mean value

$S S D_1$ is the sum of squared deviations from the sine curve

N is the number of points in the analysis.

An example of a periodogram is given in Figure 10, in which sine curves with periods from 5.0 – 37.0h in 0.1h increments have been fitted to all the readings of S8A, and in which levels of significance are also shown.

Each data series was fitted by this function in the following ways:

(a) The overall pattern of changes in temperature was assessed by analysing the complete data series of each subject.

(b) To gain estimates of trends in the Sonar Room subjects' temperature changes during the patrol, the values were divided into 3-day section.

(c) Similar estimates of trend were gained for the officers by dividing the data into 6-day sections (progressing by 3-day increments).

To distinguish between sampling artefacts and changes in the temperature rhythm caused by the watchkeeping schedule the corresponding points from the 'Standard' curve were also analysed in each of the above three sampling schemes.

## Results

### Sonar Room subjects (both patrols)

Note: Seven of the ratings took part in both patrols, so that although the data are considered as arising from 20 subjects there are only 13 different individuals.

### 1. Whole Patrols

A priori it was considered that four factors might affect the analysis of the temperature changes:

(a) entrained circadian rhythm (period 24h)

(b) data sampling patterns (as determined by the watchkeeping system: period 72h and its harmonics).

(c) within-watch effect (period 4h)

(d) modification of the circadian rhythm by the watchkeeping system and concomitant changes in habit.

Segmenting the 'Standard' curve into the watchkeeping schedule sections should mimic the first two effects but not the last two.

The data series of each subject was fitted by curves with periods ranging from 1.1h - 40.0h (assessing the fit of the circadian period and its harmonics and the harmonics of the 72h watch-keeping cycle), 70.0h - 75.0h (for an effect from the fundamental period of the watchkeeping cycle) and 164.0h - 173.0h (for weekly influence). Within these ranges increments in the period were 0.1h.

#### (a) Circadian Influence

(i) Significance of fit. The data of each subject were fitted significantly by the curve with a 24.0h period. For all except one subject (S1B) the curve was very highly significant ($p < 0.001$); for S1B the curve was significant ($0.01 < p < 0.05$). However, only 4 subjects showed their maximum F-ratios at this period: S8A, S2B, S9B and S10B.

The range of the best-fitting periods about 24.0h was 23.7 - 24.6h. Considering the first patrol only the range was 24.0 - 24.6h and for 6 of the 8 subjects the best-fitting period in this range was 24.1h. The exceptions were S8A (maximum at 24.0h) and S7A. S7A's readings were described best by a 24.6h period, supporting the impression from the initial analysis that this subject exhibited a

tendency to 'free-run' (though there was a subsidiary rise in the F-ratio which reached a peak at 24.0h). The results from the second patrol were more variable, with a range from 23.7 - 24.6h. This may have been occasioned by the fewer and less regular readings and probable temperature disturbance caused by the infection.

(ii) <u>Amplitude</u>. The amplitudes of the 24.0h period ranged from $0.07 - 0.51°F$ (that of the 'Standard' curve was $0.53°F$). The greater regularity of the first patrol is seen in the generally larger amplitudes (range $0.19 - 0.51°F$, compared with a range of $0.07 - 0.36°F$ for the second patrol).

(iii) <u>Phase</u>. The times of acrophase (maximum point on the fitted curve) of the 24.0h period were all between 15.6 and 19.5h. For the first patrol the range was 17.8 - 19.5h and for the second patrol 15.6 - 18.5h. The time of acrophase of the 'Standard' curve was 17.5h. The values for the first patrol were again more consistent. They were all later than the value for the 'Standard' curve.

(iv) <u>Individual Consistency</u>. S3A showed the best fit of the curve which also attained a maximum at 24.0h, the greatest amplitude, and an acrophase nearest to that of the 'Standard' curve. On the second patrol S9B was the most consistent subject in these respects. All other subjects were considerably less consistent than these two.

(b) <u>Other Periods</u>

Many other periods which are (approximately) harmonics of a 72h period fitted the data series significantly (see Table 3). When the 'Standard' curve was divided into the same sampling pattern the same periods emerged. It is considered that some of these periods resulted from an interaction of the sampling system with the circadian rhythm (see, for example, Figure 11).

Despite being harmonics of a 72h period neither an 8.0h nor a 4.0h period was significant for the 'Standard' curve. However, for the present data, 5 subjects on the first patrol exhibited a significant period in the range 7.7 - 8.3h and 6 subjects on the second patrol showed a period in the range 7.6 - 8.2h. A 4.0h period was shown by 10 subjects altogether.

The existence of the significant period around 4.0h could well have resulted from a systematic within-watch effect. The period around 8.0h could have resulted from an interaction between the watchkeeping system, sleeping habits, and the circadian rhythm. The most probable way in which this could give rise to an 8h period would be for temperature to be lowered at 1600 and raised at 0400h. It was noted in the analysis of sleep-patterning (described in Section A) that the ratings often slept before the 1600 - 2000 watch (making up sleep lost on night watches) and tended to stay awake before the 0400 - 0800 watch. The former habit should lower temperature at 1600, and the latter raise temperature at 0400. Also, Aschoff et al (ref 5) have demonstrated that remaining awake tends to delay the circadian rhythm, so in the latter case temperature <u>after</u> 0400 might be expected to fall rather than rise in the 'normal' manner.

A weekly period fitted only one rating's data significantly (S8B).

The data of the 20 Sonar Room subjects were divided into successive 72h sections, to determine trends during the patrols. Occasionally the data in a section for a rating on the second patrol extended over two cycles owing to the occurrence of the short infection previously mentioned. Only the parameters of the 24.0h period will be considered.

(i) <u>Significance of fit.</u> For the ratings of the first patrol 89 of the 128 cycles were fitted significantly by the sine wave with a 24.0h period.

To investigate whether there was a trend in the fit of the curve during the patrol, the Mean Square Successive Difference Ratio (MSSDR) (Refs. 6, 7 and 8) was calculated from the logarithms of the F-ratios. Only S4A and S6A showed significant trends ($\eta = 0.793$, $0.001 < p < 0.01$ and $\eta = 1.238$, $0.01 < p < 0.05$ respectively).

For the ratings of the second patrol only 74 of the 160 cycles available for analysis were significant. This confirms the poorer fit of a sine curve to the data from this patrol noted in the analysis of the whole series. The effects on temperature of the infection may have affected the values even though the subjects had returned to watchkeeping.

Subjects 9B (10 out of 13 cycles fitted significantly) and 12B (6 out of 15 cycles significant) showed significant trends in the logarithms of their F-ratios as calculated from the MSSDR. ($\eta = 0.938$, $0.001 < p < 0.01$ and $\eta = 1.096$, $0.01 < p < 0.05$ respectively).

On the second patrol there was a significant between-cycle effect ($F = 1.861$, $0.01 < p < 0.05$) for the F-ratios, but this was not evident on the first patrol. On the other hand, applying MSSDR to the mean F-ratio values showed a significant trend in the values for the first patrol ($\eta = 0.954$, $0.001 < p < 0.01$), but not for the second patrol.

(ii) <u>Amplitudes.</u> Among the ratings of the first patrol S4A, S6A and S7A showed significant trends in amplitude, according to the MSSDR ($\eta = 0.511$, $p < 0.001$, for S4A, and $\eta = 1.020$, $\eta = 1.138$, $0.01 < p < 0.05$ for S6A and S7A respectively). Inspection of the data showed that these trends represented reductions. Since S4A and S6A showed a significant trend in the fit of the curve also, it follows that only S7A demonstrated a significant trend in amplitude reduction not accompanied by a poorer fit of a sine curve to the data.

Five ratings of the second patrol showed a significant trend in amplitude: S3B, S8B, S9B, S11B and S12B. Inspection of the data showed that this trend represented a reduction throughout the patrol for S9B, S11B, S12B and S8B ($\eta = 1.108$, $0.01 < p < 0.05$; $\eta = 0.628$, $p < 0.001$; $\eta = 0.869$, $\eta = 0.979$, $0.001 < p < 0.01$ respectively), whereas S3B showed a rise again towards the end of the patrol. Since S9B and S12B showed a significant trend in the fit of the curve also, it follows that 2 of the ratings (S8B, S11B) on this patrol showed a reduction in amplitude not accompanied by a poorer fit of a sine curve to the data.

Both patrols showed significantly greater variance between cycles compared with the variance between the subjects in those cycles (first patrol $F = 3.367$, second patrol $F = 4.389$, $p < 0.001$). The mean values of the amplitudes also showed significant trends on the MSSDR (first patrol $\eta = 0.787$, $0.001 < p < 0.01$; second

patrol $\eta$ = 0.353, p<0.001). Figure 12 shows this trend in mean amplitude for the first patrol; the shape of the curve clearly indicates a reduction during the patrol, thus supporting the findings of the initial analysis based on 'range' (see Section A).

(iii) Phase. For each subject of the first patrol the modal acrophase was between 17h and 19h (the acrophase of the 'Standard' curve was 17h). The range within which acrophases occurred for different individuals varied considerably, the extremes being S8A for whom the acrophase was always between 16h and 20h, and S7A who showed a tendency to acrophases in the evening, but also at 02h, 04h, 07h, 09h and 13h. These 'aberrant' acrophases for S7A occurred in the following order; 04h, 02h, 07h, 09h and 13h, again supporting the impression gained from the initial analysis that this subject had a period greater than 24h.

Considered by cycle (Fig 13) the modal acrophases were always between 17h and 23h (except for cycle 16 for which each subject exhibited a different time of acrophase; and cycle 8 for which there were two modes at 08h and 18h). At the beginning of the patrol (cycles 1-7) all modal acrophases were between 17h and 20h with ranges from 3 to 8 hours. During the latter part of the patrol the modes were from 17h to 23h with ranges from 6 to 18 hours, and included the two cycles for which a single mode was non-existent.

Only 8 ratings on the second patrol showed a single mode in the time of acrophase; the remaining 4 showed more than one mode. The range of the single modes was 13-21h which encompassed most of the modes shown by the 4 'multi-mode' subjects. The range of times of acrophase for a single subject varied from the consistent S5B and S6B whose acrophases were always within the 8 hour range from 13-21h (modes at 21h and 18h respectively), to S12B whose times of acrophase spanned 19 hours (14-09h) and who showed 3 modes at 05h, 17h and 20h.

The times of acrophase grouped by cycle are shown in Figure 14. The phasing of these acrophases was very similar to those in the first patrol (as comparison of this Figure with Figure 13 demonstrates). The modal time of acrophase was at 17h for 4 of the 11 cycles which showed a single mode, and the range of modes was 14-21h. At the beginning of the patrol the ratings showed greater inter-subject consistency in their phasing. During the first 5 cycles the range in times of acrophase was from 9 to 13 hours, whereas later in the patrol the range was 11 to 19 hours (only 1 cycle had a range less than 14 hours). (Inter-subject consistency was greater at the beginning of the first patrol also).

Intra-subject similarity between patrols

For the 7 ratings who took part in both patrols, an attempt was made to find the second patrol code which corresponded to the known first patrol codes. This exercise was only successful for S8A who was coded S9B on the second patrol.

On both patrols this rating's temperature values maintained a 24.0h rhythm with an acrophase in the early evening. The consistency and regularity of the results from this individual contrasts with the variability shown by the other subjects. No obvious reason for this subject's unique consistency suggests itself, but examination of his personality test profile (held at Royal Victoria Hospital, Netley Abbey) might be a worthwhile exercise in view of the possible implications for selection of submarine personnel.

## Officers

Like the ratings, each officer only recorded his temperature whilst on duty, but unlike the ratings this meant that there were only readings at the same few hours each day after the first 3 days. To gain some estimate of the distortion to be expected from this limited sampling, data from the 'Standard' curve were again used for comparison. For each officer, sets of temperatures from the 'Standard' curve were taken at times when he regularly made a reading. The officers will be referred to as 01-04 and the sets of data taken from the 'Standard' curve at corresponding times as 'simulated' officers S01-S04.

## 1. Whole Patrol

The data series of each officer and of each 'simulated' officer were fitted by the same range of periods used for the ratings series: 1.1-40.0h, 70.0-75.0h and 164.0-173.0h.

### (a) Circadian Influence

(i) Significance of fit. The data of each subject were fitted very highly significantly ($p < 0.001$) by the curve with 24.0h period. For 02, 03 and the 'simulated' officers this period had the highest F-ratio amongst those tried. For 04 the maximum F-ratio was attained with a 24.2h period and 01 showed the maximum F-ratio at 24.1h. These periods greater than 24.0h calculated from the whole series may represent a phase shifting during the patrol, or they may merely be non-significant differences from 24.0h. Greater regularity of the readings of 02 and 03 could be inferred from the much higher F-ratios compared with 01 and 04 (ie F= 156.7 and 192.1 cf 16.4 and 27.1 respectively).

(ii) Amplitude. The amplitudes of the 24.0h period fitted to the 'simulated' officers are shown in Table 4 and to the real officers in Table 5. S04's amplitude was nearest to the value obtained from the 'Standard' curve and S01's value was a gross over-estimate. 02, 03 and 04's amplitudes were similar to the value for the 'Standard' curve, but 01's value was very small. This may be expected from the comparatively poor fit of the 24.0h curve to the readings of this officer.

(iii) Phase. The times of acrophase of 3 of the 'simulated' officers (S01, S02 and S04) were within 1 hour of the time calculated from the 'Standard' curve (17.3h, see Table 4). The exception was S03, whose time was 3.2 hours earlier than that of the 'Standard' curve.

In view of the closeness of these times for S01, S02 and S04, it might be expected that 01, 02 and 04 would give reasonably accurate times of acrophase. This prediction was supported for 01 and 02, whose acrophases were within an hour of the expected time, but not for 04 (see Table 5). 03's time of acrophase, on the same argument, might be expected to be about 3 hours before the expected time; and this was, in fact, the case.

When each real officer's time of acrophase was amended by the difference in time of his 'simulated' counterpart from the 'Standard' curve (see Table 5) the acrophases were observed to be at times comparable to those calculated for the ratings, except for 04.

04's time of acrophase was later than 22.0h before and after amendment. However, if the accuracy of his 'simulated' counterpart's estimation of time of acrophase compared with the 'Standard' curve is accepted, his acrophase was within 1 hour of that time, which suggests that this officer showed a phase-drift during the patrol. This is in agreement with the fact that his best fitting period was 24.2h.

b) Other Periods

Predictably, the data analysis did not show an influence from a 72h period and its harmonics, since the officers were not operating a 3-day rotating watchkeeping schedule. However, an influence from the harmonics of a 24.0h period might well be expected, since the 'simulated' officers showed major influences from this source (the 12.0h, 8.0h, 6.0h, 4.8h, 4.0h and 1.2h harmonic periods all being significant at $p < 0.001$ in each case). The analysis supported this expectation: for all four real officers the 12.0h (12.1h for 04) and 8.0h periods were very highly significant ($p < 0.001$) and the 6.0h and 1.2h periods were significant ($0.01 < p < 0.05$). For 01 periods of 12.0h, 8.0h and 4.8h actually fitted the data better than the 24.0h and 24.1h periods.

2. 6-day Sections

By dividing the data series into over-lapping 6-day sections (as described earlier) it was possible to show the adaptation of the temperatures of the officers to their 'stabilised' duty periods. Only periods in the range 23.0 - 25.0h were fitted to the data.

Officer 01

As noted above, in the analysis of the whole 30-day period the temperature changes for this subject were more irregular than those of the other officers: the amplitude of the 24.0h period was lower, and harmonics with 12.0h, 8.0h and 4.8h periods and a 24.1h period fitted the data better.

When the data for this subject was examined in 6-day sections the most notable feature was an indication of adaptation to retiring at 0300, seen by the time of acrophase (on the 24.0h period) drifting to later in the day (Figure 15). However, this subject habitually took an 'afternoon nap', and since sleep is known to lower temperature it is improbable that his maximum temperature would be between 1600 and 1900. It is more probable that his temperature was bimodal, as suggested from the 12.0h period fitting the whole series better than the 24.0h period. The variability of the afternoon nap probably accounts for much of the irregularity of the best fitting period about 24h (Fig 16). The lower amplitudes for this officer are only seen in the latter two-thirds of the patrol (Fig 17).

In sum, the analysis of this officer's data demonstrates the failings of the restricted sampling schedule. His irregular afternoon nap is probably the major cause of the irregularity. The only definite feature is that the phasing of his temperature rhythm appeared to adapt to his late retiring time.

Officer 02

As already mentioned, a 24.0h period sine curve provided the best fit to the whole data series for this subject, and the time of acrophase and amplitude were similar to those of the 'Standard' curve.

When divided into 6-day sections the best fitting period was most irregular (Fig 16),
notably during the first 9 days, but all of the best fitting periods were very highly significant
(p < 0.001). The times of acrophase showed no distinct trend. However, the amplitude
increased (Figure 17), which was due mainly to lower readings during the morning duty.

This subject did not appear to show any adaptation to his major duty period being from
0430 to 0830h. Again, acrophases between 1600 and 2100 are improbable, since the
subject regularly slept between 1300 and 1700. The observed range of times for the
acrophase for this officer must be a consequence of the sparse sampling; a strong bimodal
rhythm cannot account for the discrepancy since a 24.0h period provided the best fit to the
whole series.

### Officer 03

This officer was working and sleeping on an essentially 'normal' routine. As noted above,
a 24.0h period sine curve provided the best fit to the whole series and the amplitude was
rather high compared with the 'Standard' curve. After the time of acrophase had been
amended it was close to the time for the 'Standard' curve.

After the first 6-9 days the time of acrophase for this subject was very regular, ranging
only from 12.8 to 13.6h (Fig 15), and the best fitting period was always within 0.3h of
24.0h with p < 0.01 for every 6-day section (Fig 16). His amplitude was variable, and
showed an irregular increase (Fig 17).

This subject demonstrates the consistency that can be attained from leading an undisturbed
regular life. The increase in amplitude could be an adaptation to or a consequence of the
environment.

### Officer 04

Most of this subject's duty period was during the normal sleeping period and the changes
during the patrol are an adaptation to this new routine. As mentioned previously, from
the analysis of the whole series a 24.2h period provided the best fit to the data and the
acrophase of the 24.0h period was unusually late at 22.5h.

During the patrol the time of acrophase (assessed from 6-day periods) changed from 18.5h
to 23.6h - most of this change occurring in the first 9 days (Fig 15). The changes were
so regular that the data was further sub-divided into non-overlapping 3-day sections.
The results from this analysis are also shown in Figure 15. The changes are less regular,
the acrophase is earlier initially and adaptation essentially complete after 9 days. Most
of the irregularities in amplitude (Fig 17) occurred during this initial period also. Figure
16 shows that the adaptation to the new routine was accomplished by a period longer than
24.0h during the initial 9 days. After that the best fitting period was within 0.1h of 24.0h.
All the best fitting periods were significant (p < 0.05).

This subject clearly showed adaptation to an unusual sleep-waking pattern. Note that the
adaptation was accomplished in only about 6 days of following this pattern (it will be
recalled that the officers did not adopt their fixed duty periods until after the first 3 days
of the patrol).

Summary of Computer Analysis

1. 'Rotating' Watchkeeping Schedule

(a) Group Phenomena

(i) On both patrols both the mean amplitude of, and the mean fit of a 24.0h sine curve to the data showed (by trend analysis) a reduction throughout the patrol. Since these means were computed from the data of individual subjects treated separately, the reductions were not artefacts.

(ii) Apart from trends, on both patrols the amplitudes showed significantly greater variances between cycles (3-day periods) as compared with variances between subjects within cycles. The fact that this effect was shown only slightly in the fit of the curves to the data suggests that environmental or social factors were affecting primarily the amplitude rather than the sinusoidal nature of the variation. The depression of amplitude was a somewhat irregular phenomenon, indicated by fluctuations about the general reduction that occurred as the patrol progressed.

(iii) Inter-subject consistency in phasing was greater at the beginning of both patrols.

(iv) The UC ratings of the first patrol were more consistent in phasing, the 24.0h curves fitted the data better, and the rhythms had greater amplitudes throughout the patrol.

(b) Selected Individual Phenomena

(i) S7A, S3B, S8B and S11B showed a reduction in amplitude, but not in the fit of the sine curves.

(ii) S4A, S6A, S9B and S12B showed reductions in both amplitude and fit.

(iii) S7A apparently showed a 'free-running' rhythm with a period of 24.6h.

(iv) A within-watch effect (4h period) was shown by S1A, S3A, S10A, S4B, S5B, S6B, S7B, S8B, S10B and S11B. Since a 4.0h period was not found in the 'Standard' curve analysis, this probably indicates that physiological changes occurred during watches for these subjects.

(v) Modification of the circadian rhythm by other factors was seen in S2A, S3A, S4A, S5A, S8A, S1B, S3B, S4B, S10B and S12B. The changes in sleep – patterning occurring during the first patrol explains the presence of an 8h period for the 5 ratings from that patrol. However, it does not fully account for this period for the 5 ratings from the second patrol.

(vi) S8A was recognisable on the second patrol as S9B; this individuals' rhythm was the most consistent of all subjects, and remained normal in both amplitude and phase throughout both patrols.

## 2. 'Standing' Duty Schedules

The 4 officers represent 4 different watchkeeping schedules and only comments on the individuals are relevant.

> [Mathematical Note: The times of acrophase calculated for 01 and 02 were improbable in the life-pattern of those subjects. Sollberger (Ref 9) warned about possible distortion from computation based on only a few readings at fixed times, and the warning is certainly relevant to these two subjects.]

Officer 1:      (i)   Adapted to a late retiring time.

                    (ii)  Variability of the length of his afternoon nap probably caused the irregularity of the data.

                    (iii) Possibly developed a bi-modal rhythm.

Officer 2:      (i)   No adaption to the early duty observed.

                    (ii)  Increase in amplitude during the patrol.

Officer 3:      (i)   Essentially regular normal day duty.

                    (ii)  Increase in amplitude during the patrol.

Officer 4:      Regular adaptation to night duty occurred in about 6 days, accomplished by a lengthening of the period of the rhythm.

The differences in adaptation and regularity may represent differences in the individual officers or in the watchkeeping schedule that was worked. With only one subject per schedule these factors cannot be separated.

## CONCLUSIONS

Both the 'graphical' and the computer analyses of the temperature data from the Sonar Room subjects agreed in demonstrating that the circadian rhythm of temperature was substantially reduced in amplitude during the patrols. Only one subject proved to be a clear exception to this rule. There was also consistent evidence that the period of the rhythm exceeded 24 hours (ie 'free-ran') in at least one subject. The implications of these changes for operational efficiency (or indeed for health) are not known; but it may be of significance that the amplitude reduction observed is similar to that recorded after rapid transition through several time zones, and that 'phase-drifting' has been shown to occur in 'cave' or 'bunker' experiments where all time clues are absent. In both such situations a state of 'internal desynchronisation' of the different circadian rhythms occurs, often accompanied by feelings of lassitude which are obviously detrimental to performance. In the time-zone transition case 'adaptation' – or 're-synchronisation' of the rhythms takes place gradually over a period of some 7-10 days, as the rhythms become 're-entrained' to the local time. In the submarine this cannot of course, occur, and so it is highly probable that the state of desynchronisation persists throughout the patrol (as in the 'cave' situation). Simultaneous assessment of temperature rhythms and

those in other physiological parameters during a patrol would provide substantive evidence from which the extent of this desychrony could be ascertained, and concurrent measurements of actual (or perhaps simulated) performance would demonstrate whether, and to what degree, operational efficiency is being adversely affected by it.

Apart from the changes in temperature rhythm, the sleep logs collected during the patrols showed that in many cases the Sonar Room ratings were not taking as much 'night' sleep as was available to them, and that the average amount of sleep taken per 3-day watchkeeping cycle was varying to an undesirable extent. The detrimental effects of actual sleep-deprivation on performance efficiency are well known; less clear are the effects of substituting 'day' sleep for 'night' sleep. E.E.G. recordings of sleeping ratings during a patrol would enable the 'quality' of their day sleep to be evaluated in terms of the relative proportions, and timing of, the different sleep 'stages' during sleep periods, to compare with the 'normal night' sleep-stage pattern which is now well documented.

Finally, the question of whether the adoption of fixed 'standing' watchkeeping schedules would be advantageous, in view of the physiological changes observed in personnel following the 'traditional' 3-watch rotating system discussed above, remains an open one. Only 4 subjects (the officer subjects on the second patrol) were assigned to such a schedule, and the data obtained from them was of necessity somewhat restricted. One of these subjects was working an essentially 'normal' day routine; of the remaining three, one showed a clear, and surprisingly rapid, adaptation to his unusual sleep-waking routine; one showed no such adaptation, and one showed adaptation but accompanied by other possibly undesirable changes in his temperature rhythm. It is clearly necessary to observe a considerably larger number of subjects on standing-watch routines of various types, in a situation where it is possible to collect more extensive data from each subject than was the case in the present trials, before any firm conclusions can be drawn on this matter.

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## TABLE 1

First Patrol: Changes in mean temperature readings at the 6 different watch-times over the 48-day period (+ = rise,

− = fall, 0 = no change).

| Subject | 2400-0400 | 0400-0800 | 0800-1200 | 1200-1600 | 1600-2000 | 2000-2400 |
|---|---|---|---|---|---|---|
| 1 | + | + | − | − | 0 | − |
| 2 | + | + | + | − | + | − |
| 3 | + | + | − | − | 0 | − |
| 4 | + | + | + | − | + | + |
| 5 | + | + | − | − | − | + |
| 6 | + | + | − | 0 | − | 0 |
| 7 | + | + | 0 | − | − | − |

TABLE 2

Officers: Times of sleep and duty

| Officer | Duty time | Sleep time |
|---------|-----------|------------|
| 01 | 08.30-12.30<br>20.30-00.30 | 03.00-08.00 (plus variable afternoon nap of 2-4h) |
| 02 | 04.30-08.30<br>18.30-20.30 | 24.00-04.00<br>13.00-17.00 |
| 03 | 08.30-11.30<br>12.30-16.30 | 00.30-07.30 |
| 04 | 00.30-04.30<br>16.30-18.30 | 05.00-16.00 (broken by lunch period) |

# TABLE 3

Approximate harmonics of the 72.0h 'rotating' watchkeeping schedule with the frequency with which they emerged from the analysis of the temperature readings of the two patrols. The range considered to represent an harmonic is also given.   (* indicates that the harmonic was significant on the analysis of the 'Standard' curve).

| Period | First Patrol (N=8) | | Second Patrol (N=12) | |
| | No. subjects | Period range | No. subjects | Period range |
|---|---|---|---|---|
| *72.1h | 8 | 70.4-72.9h | 5 | 71.1-72.5h |
| *36.0h | 8 | 35.9-36.0h | 10 | 35.3-36.7h |
| *24.0h | 8 | 24.0-24.1h | 12 | 23.8-24.6h |
| *18.0h | 7 | 17.8-18.0h | 11 | 17.9-18.5h |
| *14.4h | 8 | 14.2-14.7h | 12 | 13.8-14.7h |
| *12.0h | 8 | 12.0-12.2h | 12 | 11.2-12.7h |
| *10.3h | 6 | 10.1-10.3h | 12 | 9.9-10.4h |
| * 9.0h | 8 | 9.0-9.1h | 12 | 9.0-9.1h+ |
| 8.0h | 5 | 7.7-8.3h | 6 | 7.6-8.2h |
| * 7.2h | 8 | 6.9-7.4h | 10 | 6.9-7.3h |
| 6.5h | 2 | 6.3-6.4h | 2 | 6.6h |
| 6.0h | | | 1 | 5.9h |
| 5.5h | 4 | 5.5h | 2 | 5.5-5.6h |
| 5.1h | 2 | 5.2h | 2 | 5.0-5.2h |
| 4.8h | | | | |
| 4.5h | | | | |
| 4.2h | | | 1 | 4.3h |
| 4.0h | 3 | 4.0h | 7 | 4.0h |

+ 18 subjects p< 0.001

## TABLE 4

'Simulated' Officers: amplitudes, times of acrophase and deviation of acrophase from that of the 'Standard' curve.

|  | Amplitude | Time of acrophase | Deviation from 'Standard' curve acrophase |
|---|---|---|---|
| 'Standard' curve | 0.545 | 17.3h | - |
| S01 | 0.845 | 16.6h | 0.7h |
| S02 | 0.615 | 17.3h | 0 |
| S03 | 0.594 | 14.1h | 3.2h |
| S04 | 0.552 | 16.9h | 0.4h |

## TABLE 5

Officers: amplitudes, times of acrophase and times of acrophase corrected by the deviation of his 'simulated' counterpart from the 'Standard' curve.

|    | Amplitude | Time of acrophase | Amended acrophase time |
|----|-----------|-------------------|------------------------|
| 01 | 0.240     | 15.3              | 16.0h                  |
| 02 | 0.504     | 18.4              | 18.4h                  |
| 03 | 0.723     | 13.3              | 16.5h                  |
| 04 | 0.523     | 22.5              | 22.9h                  |

DUTY PERIODS

Day No. 6

NAME _____  RATE A.B. UC². AGE ___  OFF/XO ___  DATE ___

| | 0000 | 0100 | 0200 | 0300 | 0400 | 0500 | 0600 | 0700 | 0800 | 0900 | 1000 | 1100 | 1200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TEMPERATURES | 97.2 | 97.5 | 96.5 | 96.2 | | | | | 96.2 | 96.6 | 96.8 | 97.0 | |
| CARD SORTING TIMES | 1 Mid 3 Sec. 1 Mid 1 Sec. | | | | | | | | 1 Mid 2 Sec. 1 Mid 1 Sec. | | | | |
| S/R DUTIES | | | | | | | | | | | | | |
| SLEEP | | | | | | | | | | | | | |
| CLEAN SHIP | | | | | | | | | | | | | |
| RECREATION | | | | | | | | | | | | | |
| REMARKS | | | | | | | | | | | | | |

| | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 2000 | 2100 | 2200 | 2300 | 0000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TEMPERATURES | | | | | | | | | 97.2 | 96.6 | 97.3 | 98.2 | |
| CARD SORTING TIMES | | | | | | | | | 1 Mid 2 Sec (1 mid done) .53 Sec. | | | | |
| S/R DUTIES | | | | | | | | | | | | | |
| CARD SORTING TIMES | | | | | | | | | | | | | |
| TEMPERATURES | | | | | | | | | | | | | |
| S/R DUTIES | | | | | | | | | | | | | |
| SLEEP | | | | | | | | | | | | | |
| CLEAN SHIP | | | | | | | | | | | | | |
| RECREATION | | | | | | | | | | | | | |
| REMARKS | | | | Feeling tired but not sleepy. | | | | | | | | | |

Same Times Again, @ Cannot Sleep.

FIGURE 3: FIRST PATROL: MEAN PROPORTIONS OF SLEEP TAKEN IN "NIGHT" AND "DAY" HOURS IN SUCCESSIVE 3-DAY PERIODS OF THE TRIAL (N=8).
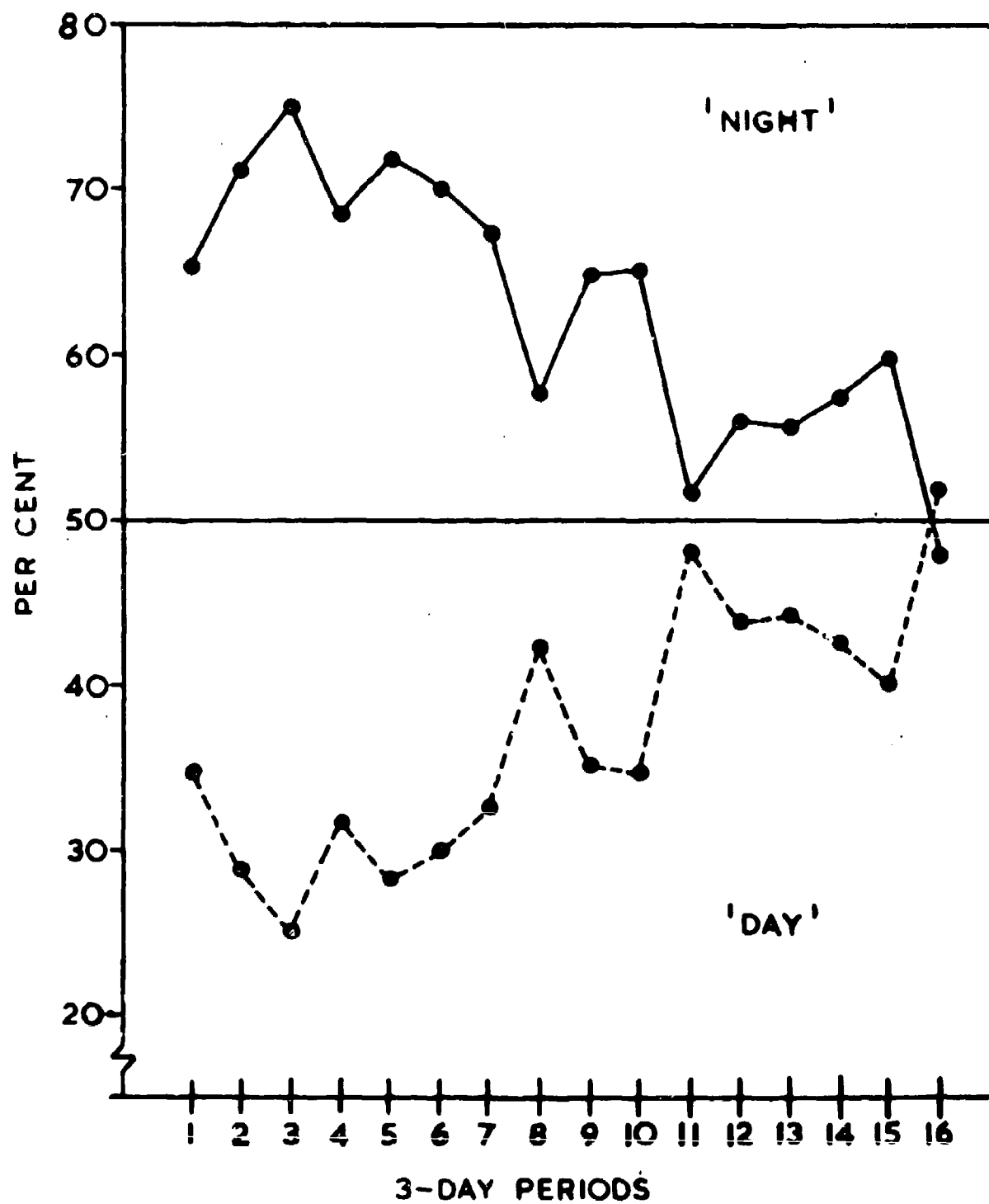
## FIGURE 4: FIRST PATROL: MEAN "24-HOUR" TEMPERATURE RHYTHM IN SUCCESSIVE 3-DAY PERIODS OF THE TRIAL (N=8).

## 3-DAY PERIODS



TIME OF DAY
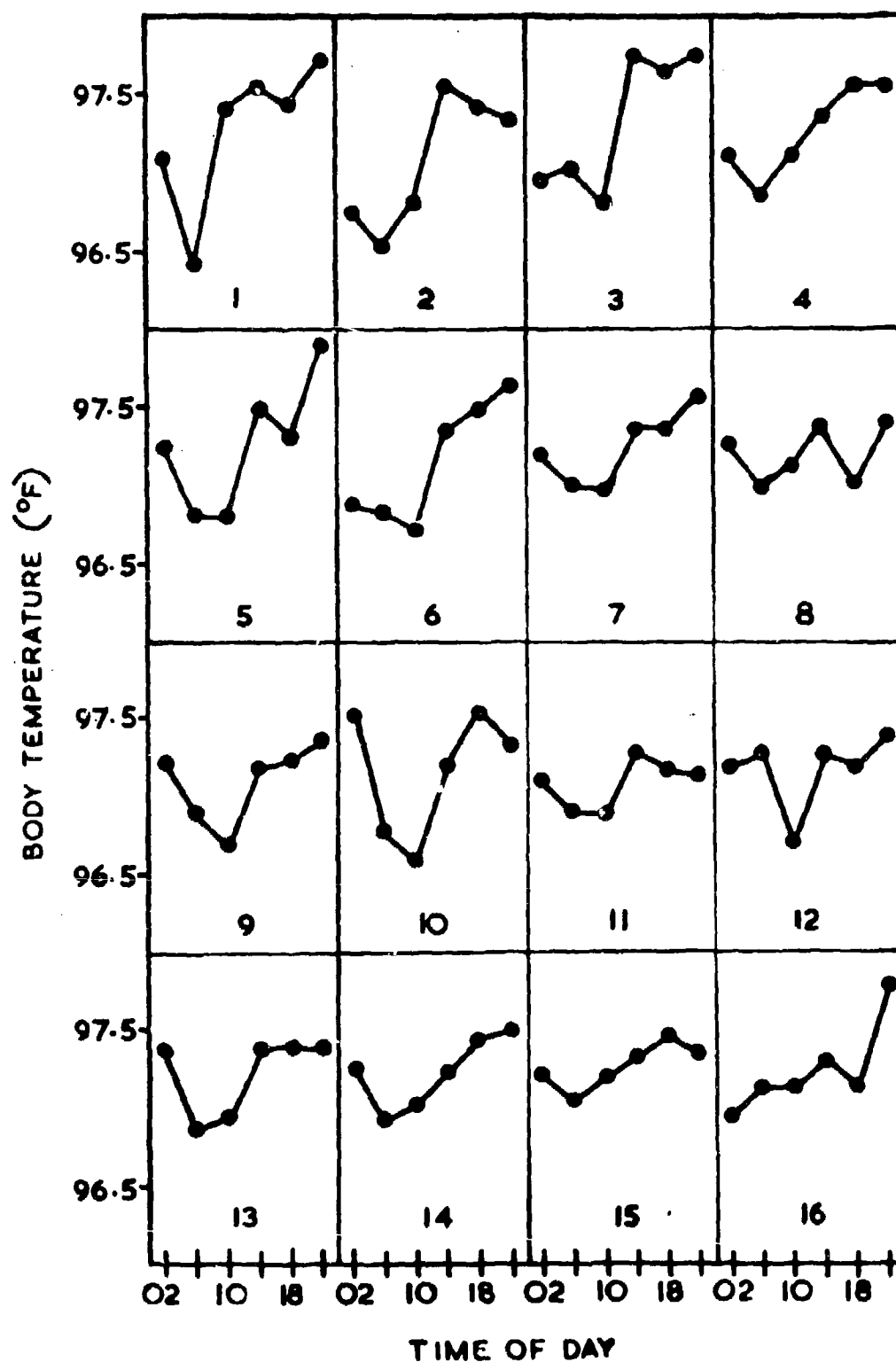
FIGURE 5: NORMAL RHYTHM OF BODY TEMPERATURE. MEAN OF 59 SUBJECTS OBSERVED ABOARD WHILE FOLLOWING "CIVILIAN" HOURS OF WORK AND SLEEP.
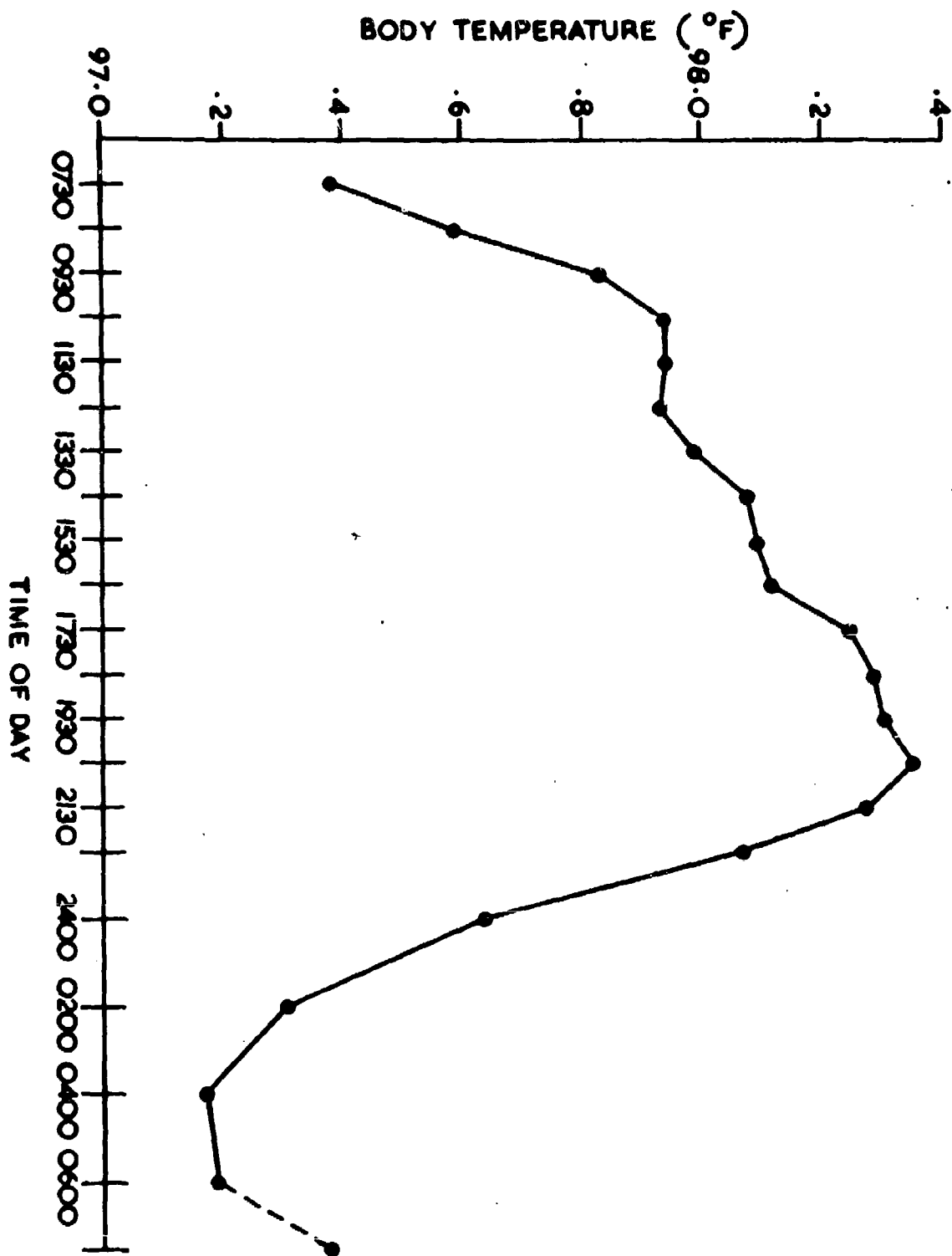
FIGURE 6:  FIRST PATROL: MEAN RANGE OF THE "24-HOUR" TEMPERATURE RHYTHM IN SUCCESSIVE 3-DAY PERIODS OF THE TRIAL (N=8).
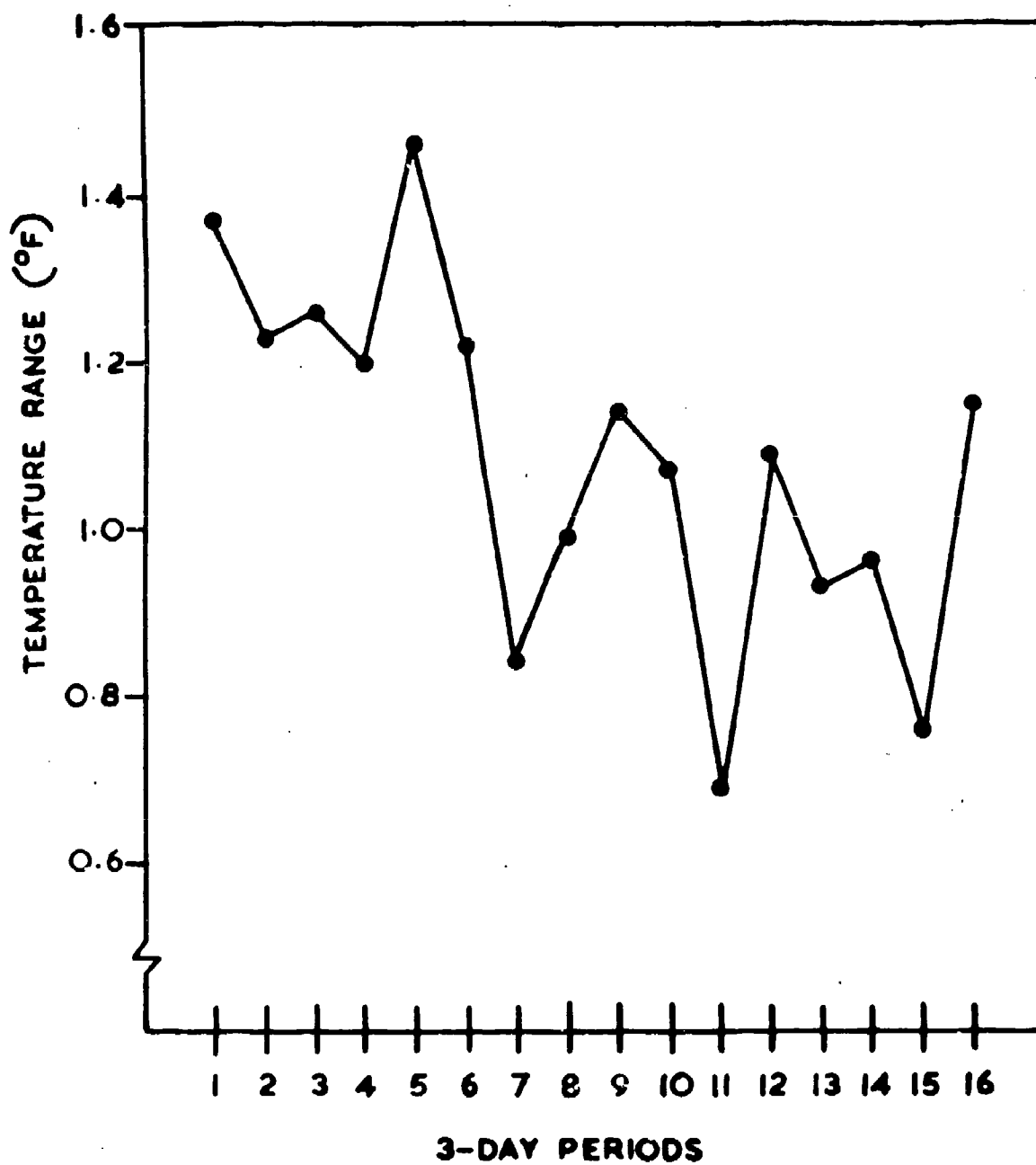
FIGURE 7: SECOND PATROL (SONAR ROOM SUBJECTS): MEAN "24-HOUR" TEMPERATURE RHYTHM IN SELECTED 3-DAY PERIODS OF THE TRIAL (N=10).
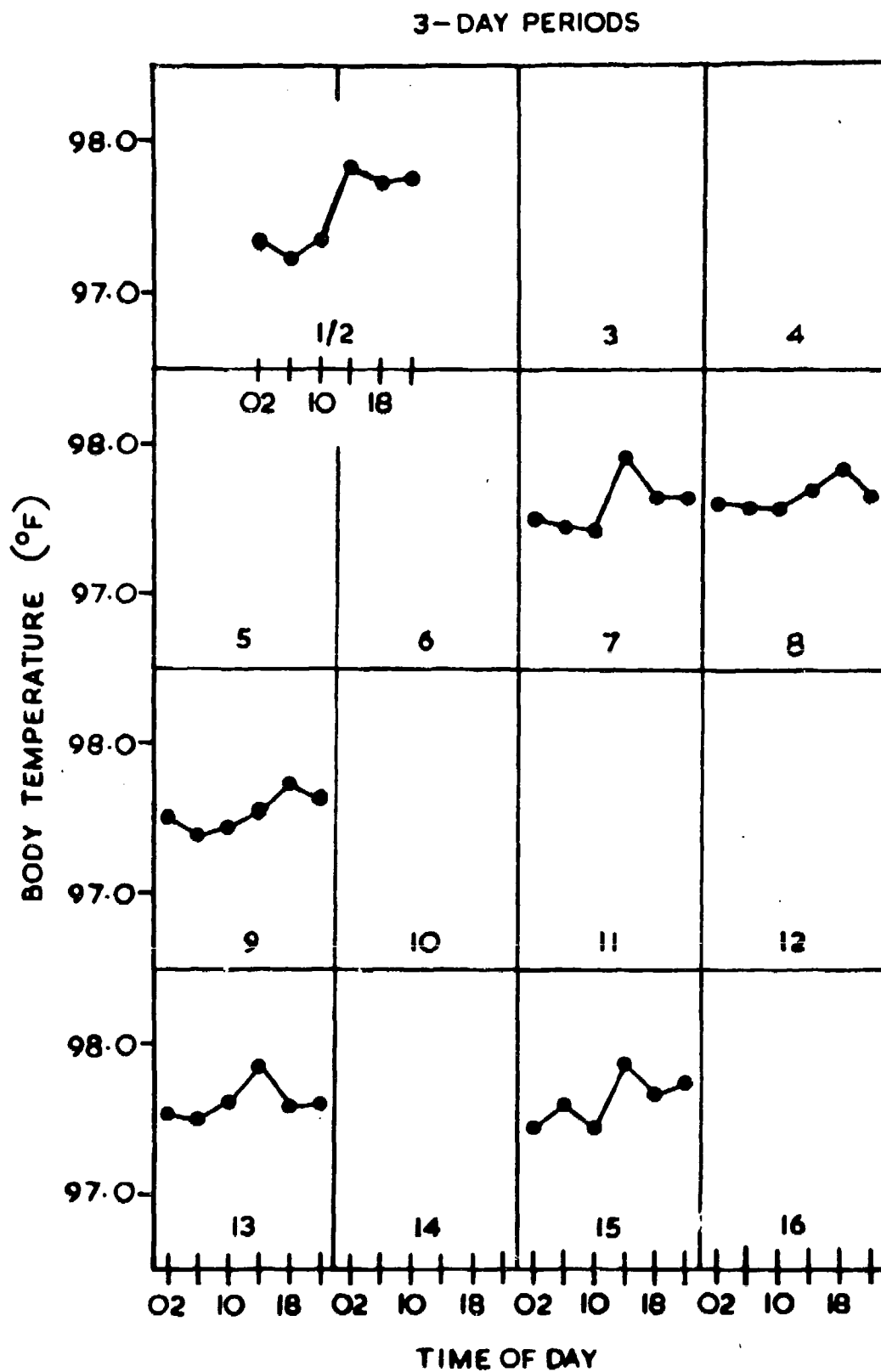
FIGURE 8: SECOND PATROL (SONAR ROOM SUBJECTS): MEAN RANGE OF THE "24-HOUR" TEMPERATURE RHYTHM IN SUCCESSIVE 3-DAY PERIODS OF THE TRIAL (N FOR EACH POINT AS INDICATED). POINTS MARKED THUS (+) ARE THE MEANS FOR THE SAME 10 INDIVIDUALS FROM WHICH THE 24-HOUR RHYTHMS IN FIGURE 7 WERE COMPUTED.
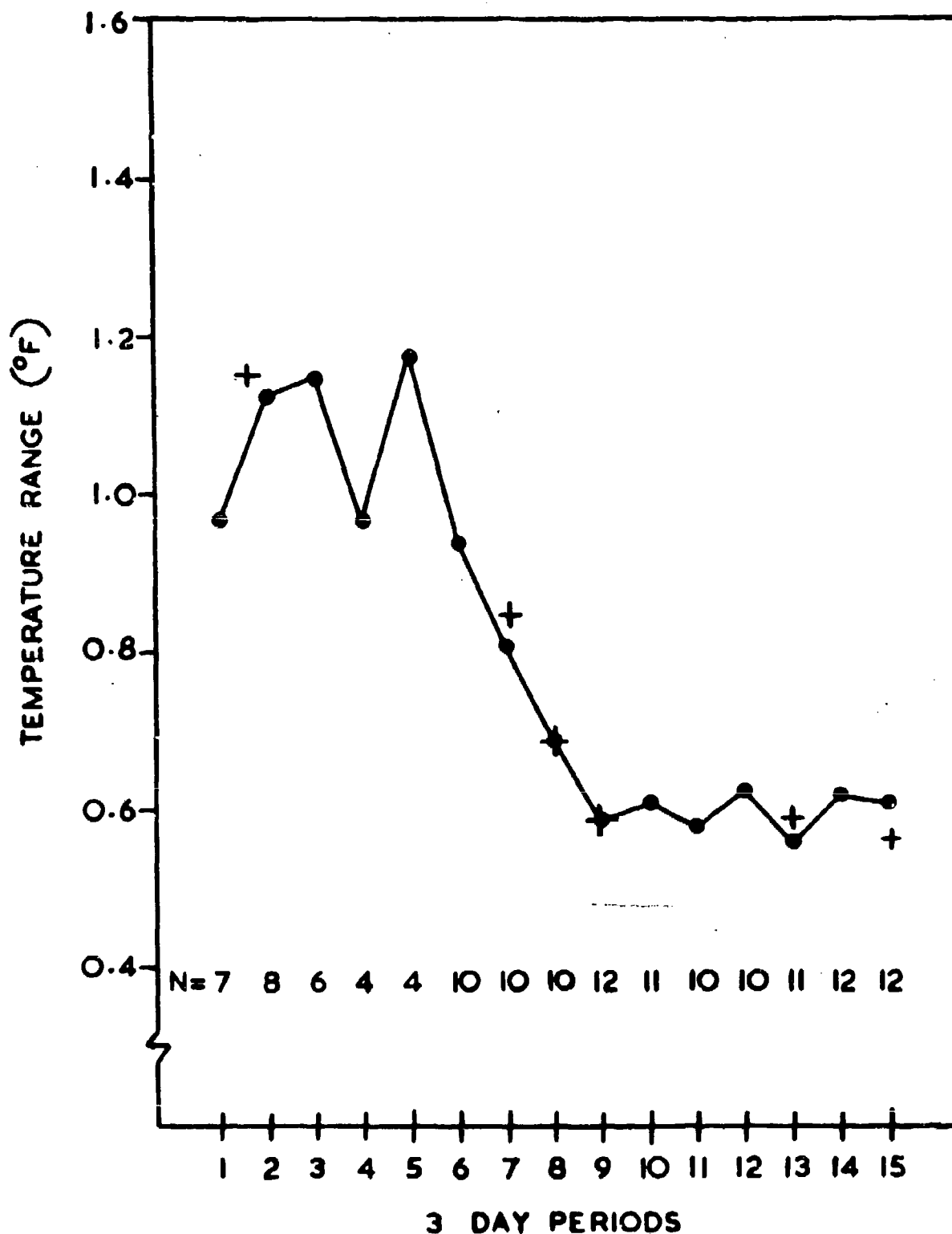
FIGURE 9: SECOND PATROL (OFFICER SUBJECTS): MEAN TEMPERATURE READINGS FOR EACH OF THE TWO DAILY
DUTY-SPELLS WORKED BY EACH SUBJECT, AVERAGED OVER SUCCESSIVE 3-DAY PERIODS OF THE TRIAL.
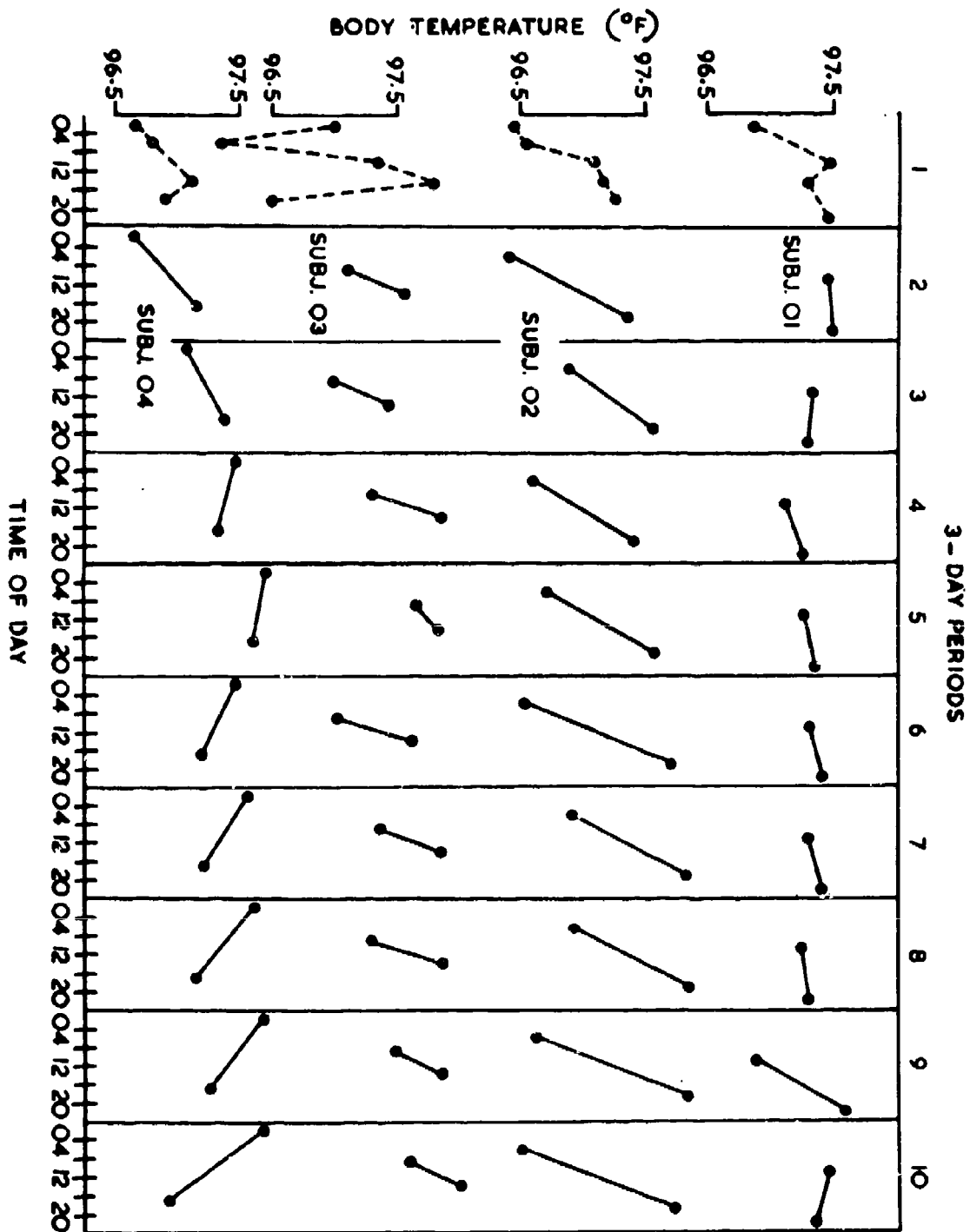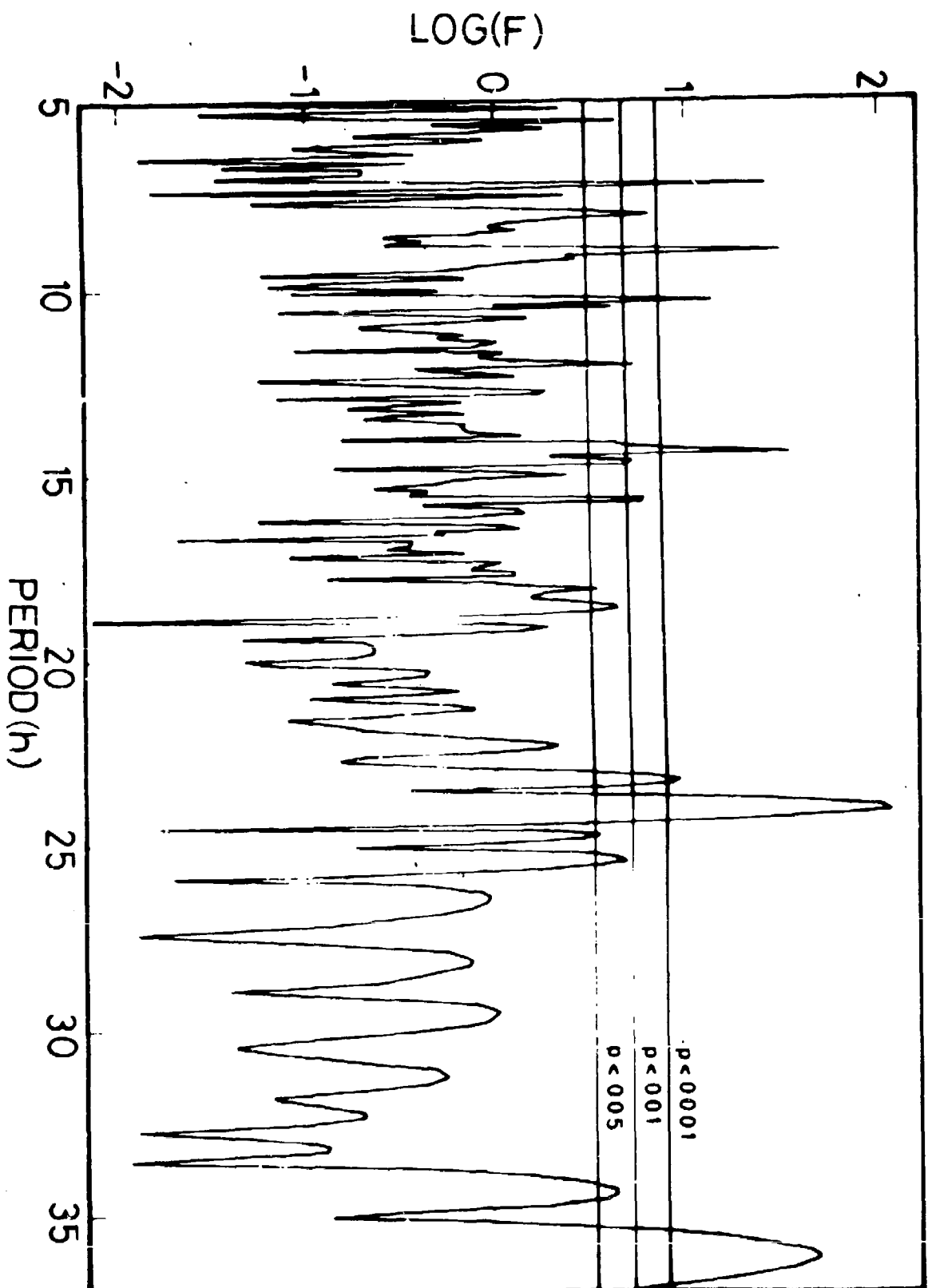
FIGURE 10: PERIODOGRAM FOR S84 ALL TEMPERATURE READINGS.
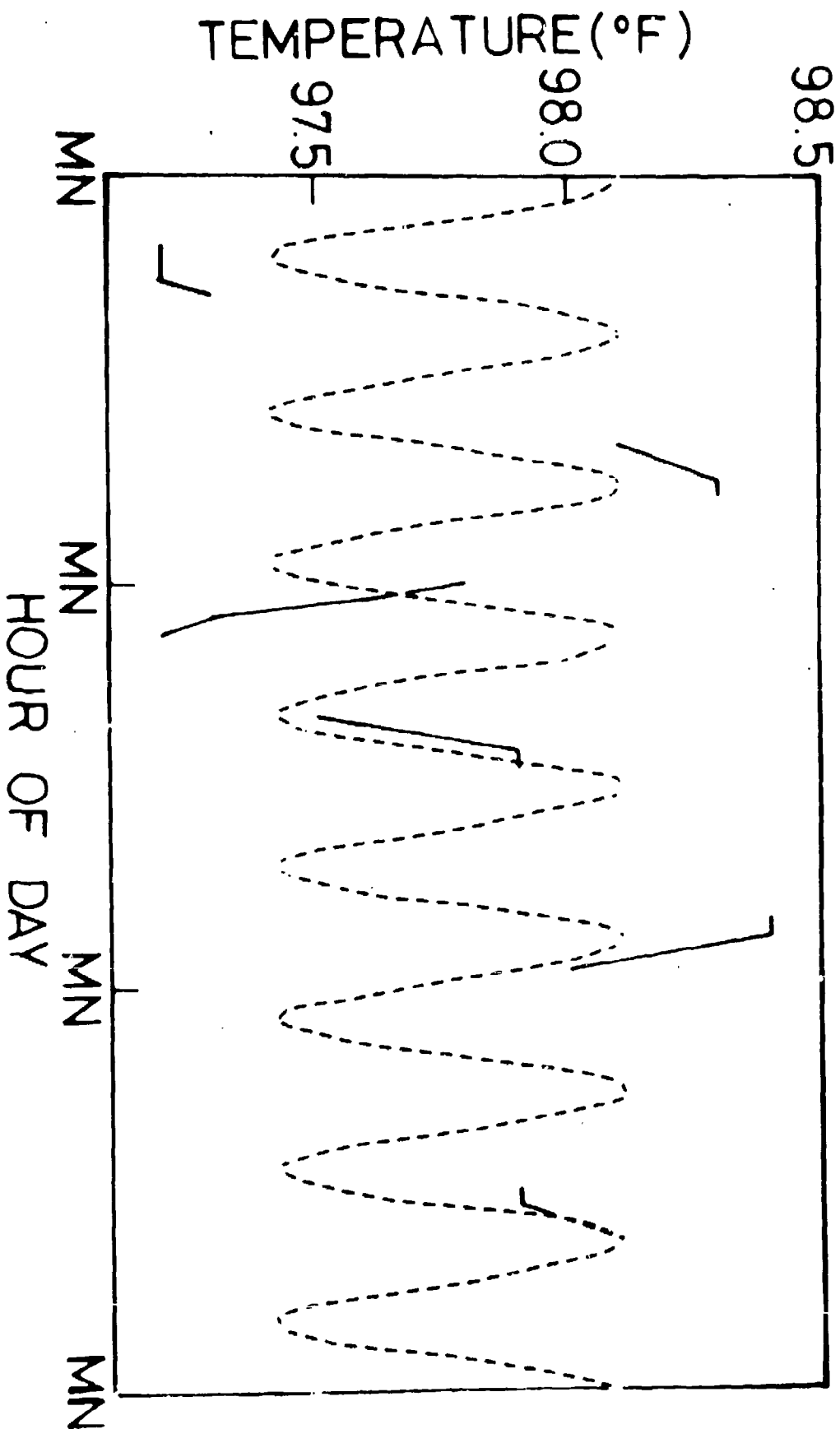
FIGURE 11: 'STANDARD' CURVE DIVIDED INTO THE 'ROTATING' SHIFT SAMPLING SEQUENCE AND FITTED BY A SINE CURVE WITH 9.0h PERIOD.
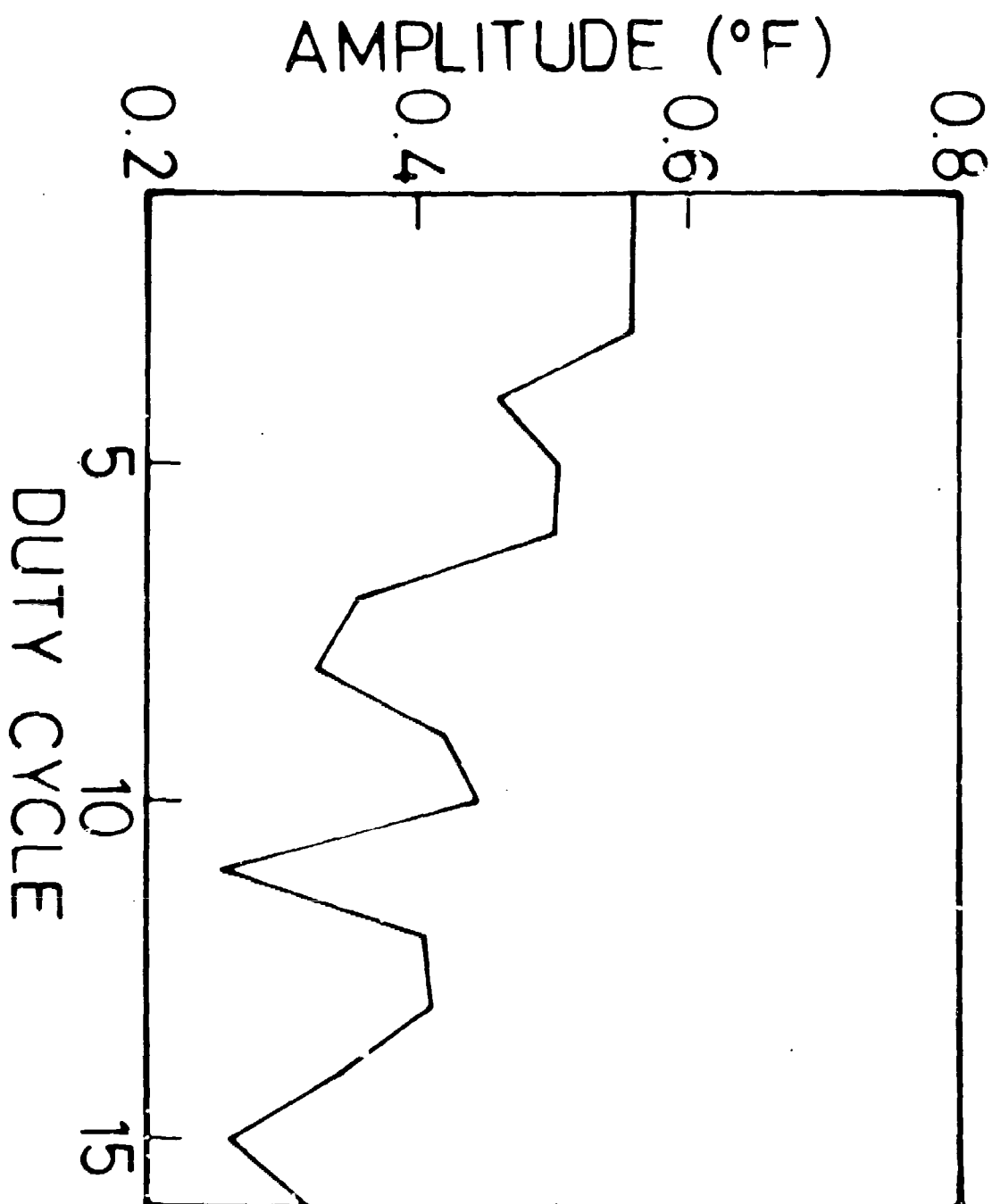
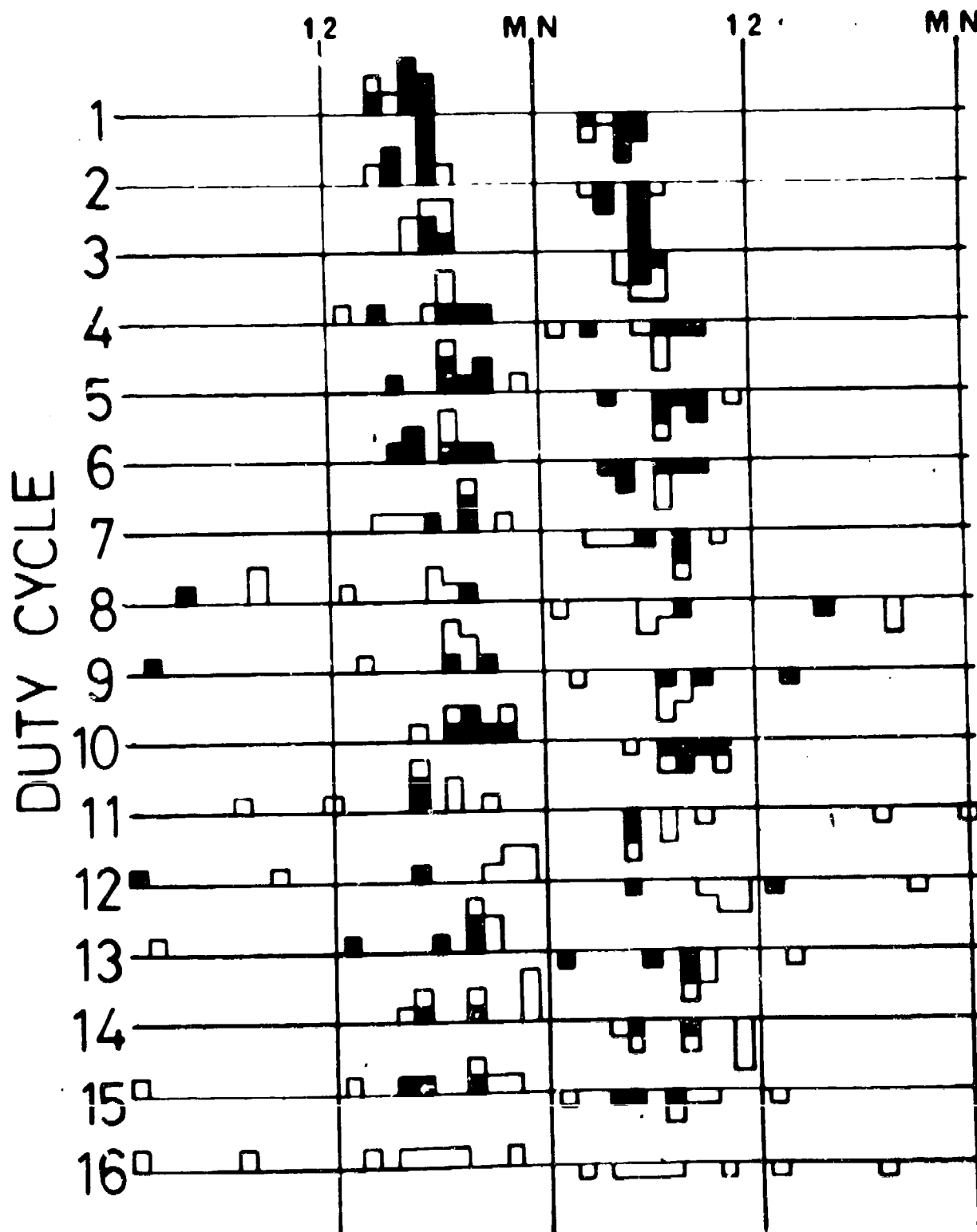FIGURE 12: FIRST PATROL: MEAN AMPLITUDE OF THE 24-HOUR SINE CURVE IN SUCCESSIVE CYCLES.

FIGURE 13: FIRST PATROL: TIMES OF MAXIMUM (ABOVE LINE) AND TIMES OF MINIMUM (BELOW LINE) ON THE SINE CURVE WITH 24.0h PERIOD. EACH SQUARE REPRESENTS ONE SUBJECT. FILLED SQUARES (■) INDICATE CURVE FIT P<0.05. OPEN SQUARES (□) INDICATE CURVE FIT N.S.

FIGURE 14: SECOND PATROL: TIMES OF MAXIMUM (ABOVE LINE) AND TIMES OF MINIMUM (BELOW LINE) ON THE SINE CURVE WITH 24.0h PERIOD. EACH SQUARE REPRESENTS ONE SUBJECT. FILLED SQUARES (■) INDICATE CURVE FIT $P < 0.05$. OPEN SQUARES (□) INDICATE CURVE FIT N.S.
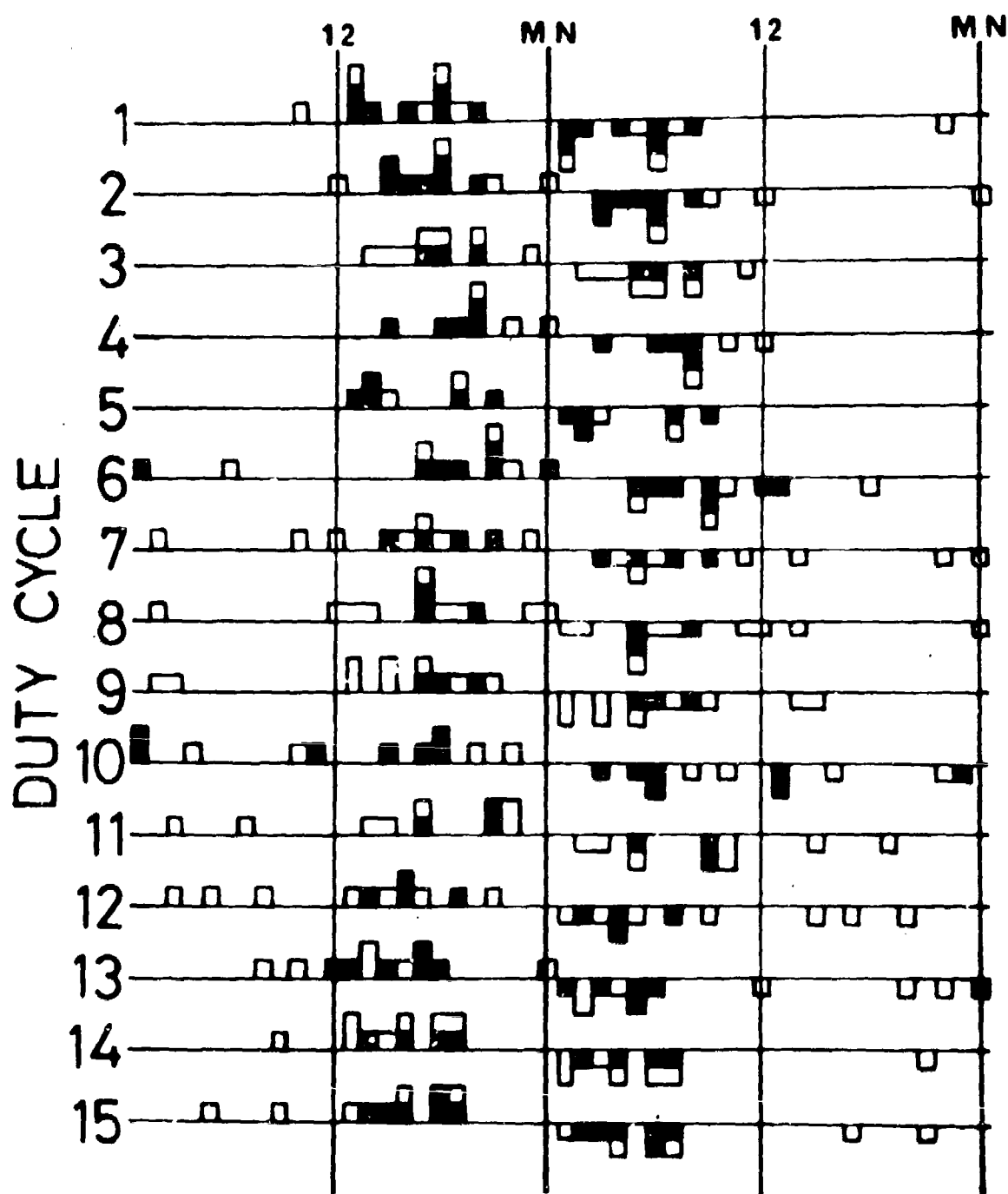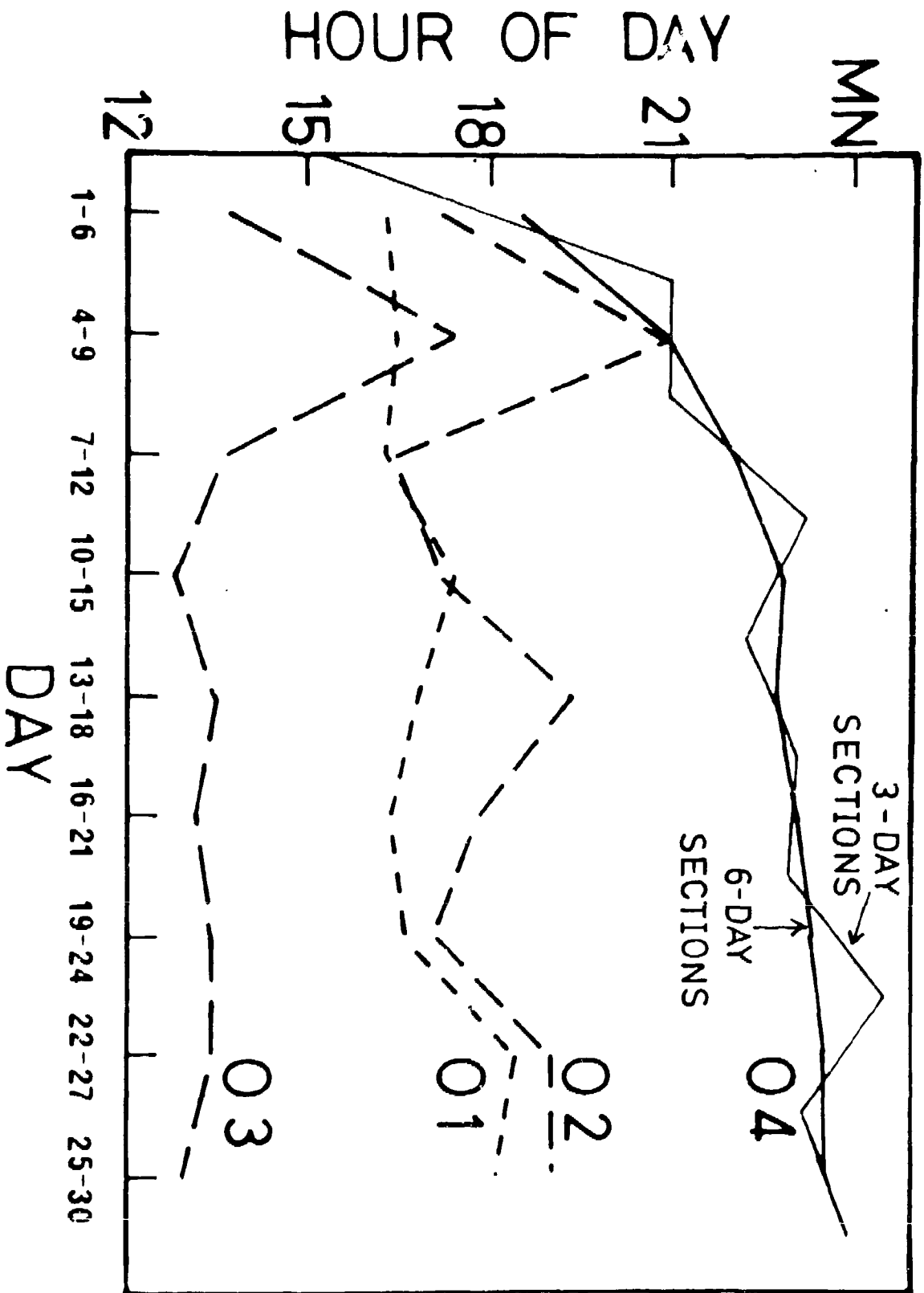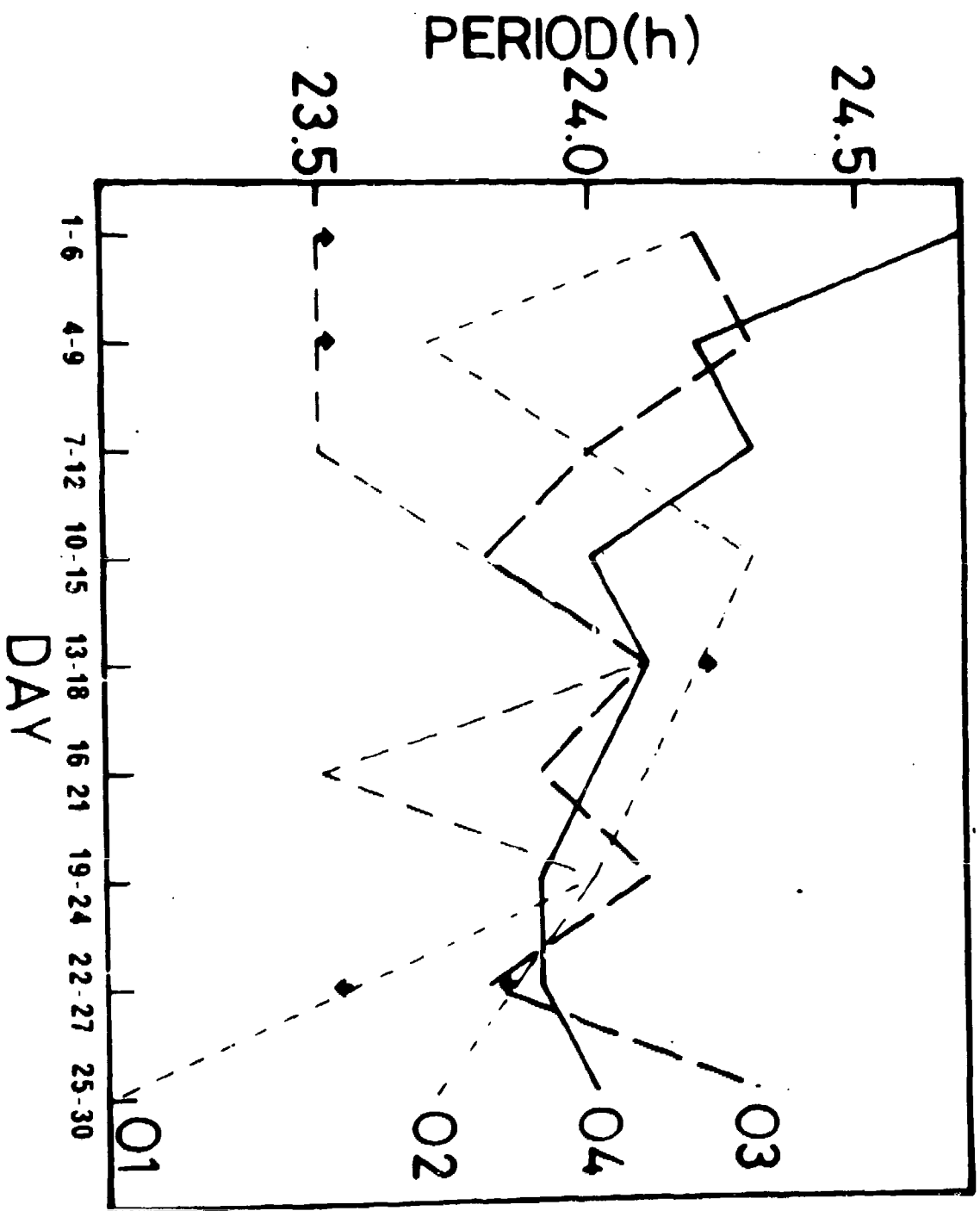
FIGURE 15: OFFICERS: TIMES OF ACROPHASE

FIGURE 16: OFFICERS: 'BEST FITTING' PERIODS AROUND 24.0h. IF THE 'BEST FITTING' PERIOD WAS OUTSIDE 23.0-25.0h RANGE IT IS INDICATED BY A DOWNWARD POINTING ARROW WHEN LESS THAN 23.0h, AND BY AN UPWARD POINTING ARROW WHEN MORE THAN 25.0h.

FIGURE 17: OFFICERS: AMPLITUDES